The Potential of 3D Visualisation Technology in Art & Design Education

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Abstract

This thesis investigates the potential of 3D visualisation technology for learning and teaching in Art and Design higher education. Unlike most educational technology studies, this research follows a learning event-centred approach as opposed to a technology centred approach. Recent studies seem to give more emphasis on the technology and less on the experience of learning and teaching. The aim of this research was not merely to employ the 3D technology but also to identify, design and evaluate an engaging and effective learning event. The technology alone cannot improve learning; therefore, it is crucial to integrate it seamlessly in an activity that is based on learning and teaching methods that are in line with the educational ethos of the academic discipline. In particular, learning and teaching in Art and Design is mainly studio-based and project-based. Educational technologies that have been successfully employed for years in other disciplines may not directly match the model of studio-based learning; this raises further challenges for educators and developers.

Three empirical studies were conducted as part of this investigation on the topics of: *Colour Theory, Colour Experience and Spatial Understanding*. The method followed here was first to identify a limitation in the current learning and teaching method, analyse the problems that learners and tutors face, and propose a solution that would improve both the learning and teaching experience. For the topics presented in this thesis, the proposed solution involved some form of 3D visualisation technology. The next stage was to design a learning activity and evaluate the effectiveness of both the activity and the technology on learning outcomes and experience. The research methods applied were primarily qualitative, in the form of observations, open-ended questionnaires, interviews and group discussions. Some quantitative data was also gathered where appropriate and possible.

The purpose of this study was to evaluate the effectiveness of the learning activity in its entirety, for learners, tutors and institutions. In addition, the type of software and hardware required is a matter of consideration since the proposed technology should be easy for students and tutors to use and feasible, physically and economically, to set up in the studio space. Apart from the learning objectives, other objectives relevant to cost and space have been taken into account in all three studies.

This research demonstrated that different educational topics may require different technological solutions. It proved that the implementation of carefully designed educational technology can enhance current learning, teaching and assessment processes by immersing students and tutors in an activity that is productive and enjoyable for both.

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Chapter 1

Introduction

This thesis presents examples of definite educational benefits achieved by designing and deploying advanced 3D visualisation technology in Art and Design education.

The hypothesis is that the implementation of carefully designed learning activities that use 3D visualisation technology can improve current learning and teaching methods by resolving existing educational problems associated with the delivery and understanding of certain art and design topics. Three topics, for which the existing teaching methods have been identified as inadequate, were chosen to investigate this hypothesis. The three studies that were conducted as part of this investigation provided favourable results with regards to the use of 3D virtual environments and spatially immersive displays for learning and teaching the chosen topics. The studies apply primarily qualitative research methods, in the form of observations, questionnaires, interviews and group discussions, while some quantitative data was also gathered where appropriate and possible.

The research questions that this investigation attempts to answer are:

Could a learning activity that uses 3D visualisation technology resolve existing problems in the delivery of certain art and design topics?

How can such a technology be successfully integrated into the studio environment?

The aim was not merely to use 3D technology but also to identify, design and evaluate an appropriate teaching approach. Technology alone cannot improve learning; therefore it is crucial to integrate it seamlessly in a learning activity that is based on teaching strategies that are in line with current learning and teaching practice. Hence, the purpose of this investigation was to evaluate the effectiveness of the learning event in its entirety, for learners, tutors and institutions. In addition, the type of software and hardware required was a matter of consideration since the proposed technology should be easy for students and tutors to use and feasible, physically and economically, to set up in the studio space. Apart from the learning outcomes and experience, other objectives relevant to cost and space have been taken into account in all three studies. This research demonstrated that different educational topics may require different 3D visualisation solutions as well as different sizes of display.

1. 3D Visualisation Technology

The term '3D visualisation technology' is defined here as meaning the authoring of 3D computer graphics (otherwise known as 3D models) that underpin the visual part of a 3D virtual application (e.g. 3D animated web graphics, interactive real-time simulations, Virtual Reality environments, shared virtual environments, etc). Depending on the purpose of the application, 3D visuals can range from simple geometrical shapes to highly detailed photorealistic models, from interactive to static, from animations to real-time simulations, etc. The first study proposes the use of a computer-based 3D learning application while the other two studies use spatially immersive displays to present real-time 3D virtual environments.

The term Virtual Environments (VE) is widely used nowadays but there is no consensus on its definition. A VE is defined here as a computer-generated, graphically rich 3D world inside which the user can explore and perform actions (e.g. interact with the virtual objects). There are different levels of immersion in VEs which depend mostly on the hardware specifications, for instance, the size of the display used. The displays can range from a typical computer monitor to a fully immersive Virtual Reality environment. This research examined the use of custom-built, off-line, non multi-user VEs for educational purposes. It tested a variety of displays from a computer screen to a widescreen wall projection to a semi-immersive Virtual Reality display. Online multi-user VEs, such as Second Life, and commercially available 3D computer games have not been explored. A description of the chosen technology is presented in Chapter 3, while definitions are also provided in the Glossary section of this thesis.

The ability of this technology to offer the third dimension, which is often neglected in traditional teaching methods, has great potential to make theoretical and abstract concepts, when they are inherently three-dimensional, more explicit for learners. Moreover, the ability to immerse the learner in a VE by using a larger display is advantageous for Art and Design areas that deal with real scale projects such as interior design.

2. Motivation

The motivation to embark on this investigation came originally from my own experience as an art and design student. During the first year of my undergraduate studies I had a somewhat stressful and unpleasant experience with one of the taught subjects: colour theory. The lectures dealt with complex and abstract concepts that had no link to the practical part of the course, which resulted in the majority of students failing to pass the exams. A few years later, during my postgraduate degree in 3D animation, I realised that some of these concepts could have been explained more effectively with the use of 3D computer models. A number of other subjects that could become more explicit and easier to understand and teach with the use of 3D visualisation technology sprang to mind (e.g. mechanical engineering, chemistry, biology, etc.).

After a preliminary literature review I found that, although in science education 3D graphics have been extensively exploited for the last two decades, in Art and Design there has been rather little research on the matter and even fewer implementations of 3D applications for educational purposes. A second finding of this initial review was that the subject of colour has been considered challenging and difficult, both to learn and to teach, hence the course I attended was not the only one facing difficulties. Therefore, the rationale for this research stemmed first from my previous experience and second from an evident gap in knowledge with regards to the pedagogical potential of 3D visualisation in Art and Design education.

3. The Scope of this Research

This research is located mainly within the context of Art and Design education, and addresses the field of 3D visualisation technology from a pedagogical viewpoint. The empirical studies were conducted in the areas of colour education and interior design education. An extended review of the advantages and limitations of the educational methods applied in these two areas was carried out.

Although the findings of this research are applicable to other disciplines and levels of education, this research mainly focuses on tertiary Art and Design education. Furthermore, the study followed a learning-event approach; the technology tested here was not evaluated from a technological but from an educational point of view by observing the learners' and the tutor's actions, and gathering their comments. The thesis discusses the appraisal of the various technical features involved (e.g. interface, interaction, navigation, quality of graphics and so on) from a pedagogical rather than a computer science perspective. Moreover, the technology, as proposed in this research, is intended to assist learning and teaching in Art and Design and not to be used as a design tool. Intrinsically, the aim is to develop the means by which the students could reach a deeper understanding of a concept, rather than providing them with a tool for designing and creating their artefacts. Of course, learning and creativity are interrelated in this discipline, so the same means could be used for learning and designing; however, the latter use of the technology is not the subject of this research.

4. Thesis Outline

4.1 Theoretical Framework

Literature Reviews

Given that this thesis is interdisciplinary, it draws on a number of discipline areas; hence the review of the relevant literatures is distributed among several different chapters because several different literatures are important to this research.

- The ethos of Art and Design education (Chapter 2)
- Educational technology in Art and Design (Chapter 3)
- 3D visualisation technology and Virtual Environments (Chapter 3)
- Colour education and colour theory courses (Chapter 4)
- Colour education in interior design (Chapter 5)
- Spatial awareness and visualisation methods in interior design and architecture education (Chapter 6)

Chapter 2: The ethos of Art and Design Education

This chapter discusses the general educational ethos that prevails in the Art and Design discipline. An overview of the core learning and teaching methods that are deeply rooted in practice-based studio education is provided. A brief analysis of the methods and theories of constructivism, problem-solving, exploratory and project-based learning is given. In addition, the role of dialogue (among learners and tutors, and among peers), as well as the tradition of 'crits' and other assessment processes will be discussed. This chapter is not meant to provide a thorough review of Art and Design education; rather, its purpose is to describe the ethos of common practice in this area and to allow the reader to appreciate that this discipline differs pedagogically from others. The chapter also touches upon the current changes in higher education and how these have effected the practice-based disciplines. Therefore, many of the commercially available learning applications may not be immediately applicable in this area.

Chapter 3: Educational technology in Art and Design

An overview of the various technologies which are often used in Art and Design education is offered in this chapter. Particular consideration is given to 3D visualisation, given that this type of technology has not been systematically used for learning and teaching in this discipline. The chapter provides examples of educational applications of 3D VEs in other discipline areas and discusses the current trends and issues in educational technology research.

4.2 Empirical Studies

Chapters 4, 5 and 6 present the three empirical studies that were conducted. As the research evolved, it naturally led to the exploration of the following subjects: *Colour Theory, Colour Experience and Spatial Understanding*. All topics involve 3D concepts/designs. The topic of Colour Theory was chosen for the first study. The conclusions of that study led to the design and evaluation of a learning activity on the effects of Colour in interior spaces, and then one finding of the second study motivated a further study that focussed on spatial awareness.

The same **methodological approach** was followed for all three studies and an effort to keep the structure of chapters 4, 5 and 6 similar has been made. The method, and in turn the structure, is:

1. Choose a topic (the selection was done on the grounds that current learning and teaching methods for this topic are inadequate and that the use of 3D visualisation might resolve some of the issues);
2. Examine how this topic is currently taught;
3. Identify the educational problem;
4. Propose a solution;
5. Design a learning activity;

6. Conduct an evaluation study; and
7. Analyse / discuss the results

While Study 1 applied both quantitative and qualitative **research methods**, in Studies 2 and 3 I used mostly open-ended measures such as observations, interviews and group discussions. Apart from attempting to gauge the learning impact, it was also important to evaluate the learning experience from the participants' point of view.

Given that the topics were different, the literature and contextual reviews, the methodology and the applied theories and research methods, all differed slightly among the studies. Therefore, it seemed more practical to offer all the information relevant to each topic within the chapter that describes the related study. This should allow each study to be read as a whole without having to refer to previous chapters.

Chapter 4: Study 1 - Colour Theory

This chapter presents a study that designed and evaluated a novel tutoring method for learning and teaching basic concepts of colour theory such as hue, saturation, value, colour systems, etc. A review on colour courses provided by Art and Design schools showed that instruction of this topic is often problematic while in some institutions it has been withdrawn from the curriculum. Educational theory was used to interpret the problem and suggest a solution, which informed the design of the learning activity. The quantitative and qualitative results from a comparative study, which involved 56 participants, are presented and discussed in this chapter. The study compared the impact of the 'Learning by Exploration' method (using initially 3D material objects) to a text version that offered the same theory. An experimental 3D digital version of the same activity was also developed and compared.

Chapter 5: Study 2 - Colour Experience

This chapter reports on the second study which designed and evaluated an educational intervention on the subject of Colour Experience in interior spaces. Initially the study reviewed the methods that are typically employed to teach colour use to interior design students and identified the educational problems in this area. Twenty 2nd year interior design students from the Glasgow School of Art (GSA) participated in a trial which required them to select a colour scheme for a 3D computer model of an interior, and then experience its effect in a semi-immersive Virtual Reality environment. The main learning objective of this activity was to raise awareness that colour is a subjective experience and that opinions of how colour may influence mood or emotion in this area may vary greatly between people. General educational principles of particular importance for this topic were constructivism in the sense of getting learners to link the topic to their own personal experiences and perceptions, and peer discussion to demonstrate how experiences varied between the participants. The chapter describes the design of the learning activity, the structure of the experiment and the technology used in the trials, and presents the findings that derived from the open-ended measures.

Chapter 6: Study 3 - Spatial Understanding

The rationale for this study arose from the findings of Study 2. The chapter presents the second study that was conducted in collaboration with the Interior Design department at the GSA. The aims of this study were twofold. First, it examined whether the ability to move inside a 3D model allows students to experience their interior designs in real-life scale and consequently offer them a deeper understanding of the practical (i.e. ergonomic) as well as the aesthetic elements (i.e. feeling of the space). Second, it compared two different spatially immersive displays: a Virtual Reality stereoscopic display (like the one used in Study 2) and a widescreen wall projection. The introductory sections of this chapter present the visualisation methods that are most often used in interior design education as well as a review of other architecture and interior design studies that have used VEs and spatially immersive displays. It then describes the design of the learning activity and reports on the qualitative data that emerged from the group discussions and observations. The chapter also presents the results of a further follow-up study that was conducted on the same topic.

Chapter 7: Conclusions

This chapter discusses the research in its entirety. It summarises the main findings and discusses the educational potential of 3D visualisation technology in Art and Design education. It then reflects on the effectiveness of the research method applied and outlines the issues and limitations of this investigation. Finally, it draws a number of conclusions about the contributions of this thesis and proposes directions for future investigations.

Chapter 2

The Ethos of Art and Design Education

How this chapter fits in the thesis

This chapter discusses the educational ethos that prevails in Art and Design higher education. It presents and discusses the core learning, teaching and assessment methods associated with the studio-based educational model employed in this discipline. The concepts of project-based learning, learning-by-doing, experiential learning, peer interaction, constructivism and assessment procedures will be raised among others. The purpose of this chapter is not to provide an exhaustive review of Art and Design education, but to set the scene by introducing the nature of the studio-based model. Moreover, this model also denotes that there are many issues involved in employing virtual learning environments or other computer-assisted learning applications in Art and Design as the adaptation of the particular educational approach can be challenging. The chapter also discusses the recent changes in higher education and how these have affected the discipline of Art and Design.

1. The Art and Design Subject

Art and design is a subject that embraces an overlapping and changing community of many disciplines. It also relates with subjects such as media and communications; the performing arts; the built environment; information technology and computing; engineering; business; and, notably, the history of art, architecture and design. *'Higher education programmes in Art and Design are currently provided by a range of institutions which include universities, institutes and colleges of higher education, specialist schools, colleges and institutes of Art and Design, and colleges of further education in partnership with higher education institutions with degree awarding powers'*(QAA, 2008, p 2).

The boundaries of Art and Design have become increasingly blurred, and many disciplines within the subject have become generic and interdisciplinary. New media and technologies have been increasingly permeating this domain resulting in replacing some of the traditional discipline-specific skills with skills of a more generic nature. The Subject Benchmark Statement for Art and Design published by the Quality Assurance Agency for Higher Education notes that *'Art and design has to varying degrees responded to, assimilated, manipulated and appropriated the creative potential of many of these technologies as they have emerged, prompting the advent of new disciplines - a process which can be expected to continue in tandem with further technological innovation'* (QAA, 2008, p. 5). Due to the unique nature of this subject the learning, teaching and assessment methods are somewhat different to other disciplines. The following sections of this chapter discuss the ethos of Art and Design education.

2. Studio-based Learning

The art and design studio *is 'both a process and a place'* (Sara, 2006, p. 325). Historically, this model of learning and teaching can be traced back to the 19th century and the École des Beaux-Arts, when the students observed and worked alongside the master artist in the atelier. Since the Bauhaus period there has been a shift in the educational aims giving more emphasis to conceptual work rather than acquisition of skills. Although this may have changed the nature of studio practice, the use of a central physical space where students can develop ideas, test concepts and undertake projects in a professional manner remains central to Art and Design education (Cunliffe-Charlesworth, 2006, pp. 122-123).

Studio-based activities are a significant feature of Art and Design education. They provide loci for both individual and group tuition. The QAA states that effective learning environments are engendered in studios, workshops, production units and computing units, with staff and students sharing experiences as partners in the process of learning (QAA, 2008,

p. 10). The studio is a setting where students spend a large amount of their time brainstorming, designing, creating, making and communicating with each other with varied levels of intervention from tutors and occasionally external critics, in events such as design reviews and crits (Schön, 1985; Sara, 2006, p. 325). It is a multi-functional space; studio-based learning and teaching happens through formal sessions (e.g. demonstrations, workshops, lectures, etc) and informal discussions with staff and peers (Cunliffe-Charlesworth, 2006).

As a process, it is normally based around project-based learning. Art and Design education is organised around manageable projects, individual or collaborative, which are closely patterned on projects drawn from actual practice (Schön, 1985, p. 31-32). Students learn the process of design through their engagement with the project. It is generally accepted that learning in Art and Design is experiential (Kolb, 1984). The educational strategies of 'learning by doing' and 'learning through practice' are central in this discipline. This learning and teaching philosophy places itself naturally within the constructivist[1] theory of cognition.

The studio is not only a working space; it is also a place for sharing critical engagement with peers and tutors which reflects many aspects of the professional art and design spaces (Cunliffe-Charlesworth, 2006, pp. 123). Peer interaction and assessment are important aspects within this learning environment. The studio, as a social learning environment, also aids retention by encouraging participation, attendance, student interaction and peer support (Cunliffe-Charlesworth, 2006, pp. 133).

Therefore, it would seem that the educational model adopted by this discipline has many benefits as it incorporates principles of good learning and teaching practice as described in the most popular and successful cognition theories. The nature of the domain, which is highly practice-based, fits effortlessly with the studio-based learning method. Other disciplines have attempted to follow this pedagogical framework by employing project-based and learner-centred learning. However, some of these characteristics and features that are central to Art and Design education are threatened by recent changes in the higher education sector. These are further discussed in the last section of this chapter.

3. Project-based Learning

One of the key educational strategies in Art and Design is *project-based learning.* The assignments in Art and Design are given in the form of project briefs. The projects are problem-based. The brief outlines a set of design requirements for which students have to

[1] The theory of constructivism is discussed in a subsequent section.

develop their own versions and solutions to a given problem (Schön, 1985, p. 32). At the start, students begin by being ‘taught’ a range of techniques and skills necessary to carry out the project. The learners may be asked to work individually or in groups. Staff and students usually meet regularly to review the projects before the final submission. The level of guidance reduces over the length of the course.

Sara (2006), who explored studio teaching methodologies across the Art and Design disciplines, observed that the model has many similarities to problem-based learning. The idea of this learning method is that the starting point for learning should be a problem that the learner wishes to answer or resolve. In particular, in project-based learning, the belief is that knowledge develops through working on the problem whereas in typical problem solving it is assumed that the student must have the knowledge in order to resolve the problem (Sara, 2006, p. 336). She noticed that there is a significant difference between the two models as design problem-based learning is mainly about problem-finding as Schön states in his book *The Design Studio* (1985) and not about problem-solving. In essence, during the process of finding a solution to the project brief, the student first explores and develops it by working out his or her own interpretation of the problem (Sara, 2006, p. 336).

According to Davies (2002), some design tutors believe that learning is best achieved when students focus their work on solving the problems outlined in the brief (which is meant to mirror practices in the industry). The role of the tutor in this case is dual: he is a senior manager as well as a client. While this approach gives more emphasis to identifying problems and trying to satisfy what other people want, other educators focus on helping students to develop and change their understanding of the nature of design through problem-finding. This attitude to problem-based learning shifts the focus on construction of personal understandings through interpretation and experimentation. In this case the student is encouraged to find a range of alternative solutions to the project brief (Davies, 2002). Essentially, the process is ‘problem-finding’ rather than problem solving, whereby the design may be exploring particular issues in relation to the theme rather than providing solutions to a given problem (Sara, 2006, p. 333).

4. Learning by Doing

Schön (1985) refers to the practice of designing as *‘learning by doing’*. The concept of ‘learning by doing’ was long established in traditional craft-based learning and teaching models. This is also in line with the educational theory of *experiential learning*. Experiential learning refers to learning in which the learner is directly in touch with the realities being studied (Keeton & Tate, 1978, p. 2). Kolb (1984) supported the theory that learners engage more with the learning process when they take ownership of a project or task and are allowed to make discoveries for themselves. The mental engagement of an experiential learner can involve questioning, investigation, experimentation, problem-solving, assuming responsibility, creativity and the construction of meaning. It is contrasted with learning in which the learner only reads about, hears about, talks about, or writes about these realities, concepts and phenomena, but never comes to contact with them as part of the learning process. This educational strategy allows for spontaneous opportunities for learning to arise, whether from unplanned moments, natural consequences, mistakes or successes.

Particular emphasis is given on acquisition of knowledge through reflection on the action (i.e. designing). The learner by engaging in the action and by reflecting on that action is expected to achieve a deeper understanding of the theory and practice involved. Schön (1985, p. 52) uses the term *'reflection-in-action'* to refer to this process. Both student and tutor are reflecting-in-action. For the students this process is like a reflective conversation between them and the materials of the situation. For the tutor it is a process of discovery of what the student understands, what his/her problems might be and what he/she needs to know to resolve them. The tutor's interventions are seen as experiments which test both his/her grasp of the student's understanding and the effectiveness of the intervention (Schön, 1985, p. 63). In order for reflection to take place, one should not work in isolation but engage in *dialogue* with his/her peers, tutors and people outside the area who might offer a different perspective to the topic under investigation.

Through this experiential, problem and enquiry-based learning approach, students are encouraged to develop both the capacity for independent learning and the ability to work with others. They are called to develop the ability to solve set problems in a creative way, but also to develop the ability to identify and redefine problems, and to raise and address appropriate issues (QAA, 2008, p. 3).

5. Dialogue

'Learning in the studio can be seen as a form of dialogue' (Sara, 2006, p. 336). This is similar to the notion of Socratic questioning[2] where the learner, by answering a series of probe questions, recovers knowledge that was already in him/her but was forgotten. Therefore, the role of the tutor is not to provide the answers but to elicit the process of self discovery in the learners, which in turn leads to a deep approach to learning (Biggs, 2003, p. 16). This dialogue is a characteristic of the studio setting where concepts and proposals are displayed to peers and

[2] The notion of Socratic Questioning is discussed further in Chapter 4, section 5.2.

tutors. According to Sara's research *'tutors and students particularly value the way that the studio involves an inherent element of public display'* (2006, p. 336-337). This raises opportunities for informal critique and development in addition to formal assessment. Moreover, this process by eliciting a deep approach to learning fosters critical thinking and conceptual change.

6. Constructivism

The learning and teaching methods in Art and Design are also in alignment with the educational theory of *constructivism*. Taking into account that this theory has also strong implications for educational technology research and development - a central area in this thesis - this section discusses in more detail the pedagogical concepts involved. Even though this theory is not new, the latest advances in technology have contributed to the creation of learning and teaching methods in which this theory can be applied more meaningfully than before.

According to the theory of constructivism, learning is a process of constructing new knowledge and understanding based on what the learner already knows and believes (Larochelle et al. 1998). The constructivist view of learning can be further explained in terms of three broad principles which are based on the theories of Kant, Dewey, Piaget and Vygotsky (Dalgarno, 2002, p.2). The fundamental principle is that each person constructs their own understanding of the world and builds his/her own personal representations of knowledge. This principle was originally articulated by Kant and was later adopted by Dewey (1966). The second principle is that learning occurs when the learner actively explores the knowledge domain leading to the discovery of a deficiency in their knowledge or an inconsistency between their current knowledge representation and their experience. People come to formal education with a range of prior knowledge, skills, beliefs and concepts that significantly influence what they notice about the environment and how they interpret it. This also affects their abilities to remember, reason, solve problems and acquire new knowledge (Bransford et al. 1999). Hence, according to Piaget, engagement with the knowledge domain exposes the 'gap' between prior and new knowledge (Dalgarno, 2002, p.2). The third principle (social constructivism), normally attributed to Vygotsky (1978), is that learning occurs within a social context, and that interaction between learners and their peers is a necessary part of the learning process.

The following points could be considered as a synthesis and synopsis of the characteristics that form the philosophy of (social) constructivism as presented in the literature (Dalgarno, 2002; Fosnot, 1996; Larochelle et al. 1998; Jonassen & Duffy, 1992; Dede, 1995; Vygotsky, 1978; Dewey, 1966):

- People use prior knowledge, beliefs and skills to construct new knowledge;
- The learner plays a central role in mediating and controlling learning (learner-centred approach);
- Multiple perspectives and representations of concepts and content are presented and encouraged;
- Meaning requires understanding 'wholes' as well as 'parts'. Parts must be also understood in the context of wholes. Therefore, the learning process focuses on primary concepts not isolated facts;
- The focus is on knowledge construction and not reproduction;
- Educators are seen as guides, tutors and facilitators. Their role is to provide guidance and support students to make sense of the new knowledge themselves;
- Activities, tools and learning environments that encourage self-paced exploration and discovery can assist learners to interpret new knowledge. Experimentation is encouraged as it can lead to deeper understanding and retention of knowledge;
- Collaborative and cooperative learning are favoured in order to expose learners to alternative viewpoints;

In contrast to constructivism, is the theory of be*haviourism* where the mind is seen as an empty vessel, a 'tabula rasa' to be filled or as a mirror reflecting reality (Fontana, 1984). Learning in this situation is conceived as a process of changing or conditioning observable behaviour by responding to stimuli from the environment. *Behaviourism* relies mostly on the 'instructionist' approach, which is largely passive, teacher-oriented and controlled. Similarly, *objectivism* believes that people hold 'the same' prior knowledge about the world and assumes that all learners gain the same understanding after instruction. This leads to a very stereotyped image of education, where the educators' role is merely to transmit new knowledge and the learners' role to accumulate this knowledge.

The studio-based model of learning and constructivism are intuitively implicit in Art and Design education. However, researchers have noticed that some art and design tutors give more emphasis on teaching technical processes and skills rather than adopting cognitive processes which are grounded in beliefs, needs and purposes. Wilson (2002, p. 402) argues that since teaching is often modelled on previous experiences of learning (the way the tutors were taught when they were students), '*it is not surprising that Art and Design tutors would prefer this learning style orientation and develop teaching strategies that replicate the master/apprenticeship model of the traditional art and design school'.* These tutors justify this somewhat 'instructionist' approach by explaining that, without basic skills, students are unlikely to find employment in the industry or be able to engage meaningfully in the projects (Davies, 2002). This approach was predominant in design education in the UK until recently but the current educational agendas in higher education aim to promote high quality learning to encourage students not only to reflect on the subject of Art and Design but also to become autonomous learners within the wider community.

7. Assessment

This section refers to the methods of assessment that are most commonly applied to Art and Design education. Assessment is seen as part of the learning and teaching experience. The practice-based nature of the discipline as well as the learning and teaching methods necessitate the employment of techniques that share the same philosophy. In addition, most educational research carried out in this area is also conducted using primarily phenomenological and qualitative research methods.

Assessment in Art and Design education is inherently problematic and has been the subject of investigation of a number of studies. As Rayment & Britton (2007, p. 41) state the *'Concepts of art and assessment are mutually and implacably hostile. Assessment seeks to objectify and define, and when applied to art, it tends to regulate and constrain an activity which is essentially autonomous and open-ended'.* Nevertheless, the discipline uses a number of formative and summative assessment methods, some involving also self- and peer assessment.

Formative assessment is usually continuous throughout the course of a learning activity. It has been recognised by most Art and Design educators that formative assessment is particularly constructive. It is concerned with providing ongoing feedback during the process of making rather than assessing and grading an isolated finished product. Formative assessment plays an integral part in the construction of knowledge and reflection-in-action.

Peer and self-assessment is prevalent throughout Art and Design education. This is largely inherent in studio-based learning where students can freely view the work of their peers. '*Consciously or subconsciously this offers students a range of benchmarks and helps them position their own achievements against others'*, which consequently develops their critical self-awareness (Fisher, 2006, p. 530). Most peer assessment happens naturally through informal discussions (about each others' ideas and work) taking place in the studio environment. Group crits can be considered as a more formal type of peer assessment. Fisher (2007) argues that although self-assessment has currently been part of the assessment process of many institutions, only on few occasions the marks count in an aggregation with other marks.

Blythman et al. (2007, p. 4-5) conducted a study to examine the assessment methods in Art and Design higher education, concentrating more on the 'crit' (short for 'critique'). The 'crit' is the most common method of assessment in practice-based domains. The authors recognised the following types of crit:

One-to-one crits: these are face-to-face discussions between tutor and student.

Formative crits: these usually take place at some interim stage during a project before work is submitted for summative assessment. This is the most common form of crit. It allows students to reflect, critically evaluate and move forward with their work.

Summative crits: these are formal assessment sessions where a mark or grade is given for the work. This usually happens after the student has presented his/her work, or staff may look and grade the work after feedback has been given to the student.

Industry project crits: these are often conducted in architecture and design courses. One or more professionals from industry are invited to attend the crit, critique the work and give feedback to the students.

Group crits: these are the most common form of crits, where a group of students attends a crit run by one or more tutors. Usually students present their work in front of their tutors and peers and receive feedback from tutors and/or student peers.

Peer crits: these crits are led by the students while the tutor acts as a facilitator. Usually the student year group is divided into smaller groups and then each group critiques the work of those in their own group or the work of those in another group. It is important that the students are given an agreed set of criteria prior to the crit. When queries arise the tutor contributes in the discussion. Peers may give feedback to the group verbally or often through written comments given to the individual student through anonymous sheets or post-its. The students believe that anonymous feedback is generally more honest.

Online crits: this form of crit is becoming more popular recently as most Art and Design institutions now have a virtual learning environment where work can be uploaded and critiqued online.

It becomes apparent that this form of assessment is very different to those applied in other disciplines. In Art and Design the student and his/her work are being critiqued in front of an audience (tutors, peers, professionals) which often can be a stressful experience. For this reason, the study of Blythman et al. (2007) also collected and analysed the views and experience of staff and students about the crits. The tutors see the crits as an opportunity for students to practise their presentation skills, to articulate their thoughts to an audience, to critically reflect and to receive formative feedback (Blair, 2006, p. 107). On the contrary, many students see the crits as confrontational experiences where they have to ‘defend’ their actions, rather than discuss or reflect on the process of learning (Percy, 2004).

Therefore, it is debatable whether this type of assessment promotes a deep approach to learning since it seems that the resulting outcome of each project (e.g. a painting, a photograph, a textile design, a piece of jewellery, etc) becomes the principal element in the assessment process. Grades are awarded towards the 'quality' of the ‘artefact’ rather than the entire art and design learning process (Davies, 2002). Thus, students are likely to spend more time on the presentation stage, as it can be interpreted as being the product for assessment. Few appear to realise that the levels of engagement with the different stages and the design and creative processes holistically can be implicit in the resulting product. There are increasing attempts to make assessment criteria more explicit to shift the weight from assessing primarily the finished artefact to evaluating the whole learning and designing process.

8. The Effect of Current Changes in Art and Design Education

According to the QAA, the Art and Design sector has made a significant contribution to the higher education agenda in the UK and is a valued member of the higher education community. The current changes in the socio-economic trends have resulted in adjustments and reconfigurations of the Art and Design curricula. The creative and cultural industries sector is continually expanding at a fast rate due to the increasing demand for visual communication, rapid developments in technology, expanding public interests in the visual arts and media, and *‘a growing awareness of what creativity and innovation can bring to many different industrial, commercial and service sectors’* (QAA, 2008, p. 3). These trends have contributed to an increased interest for education in the subject, which resulted in a raise in the number of students attending courses in Art and Design during the last decade. Figure 2.1, 2.2 and 2.3 show this gradual increase for the period 2008-1996 (HESA, 2009).

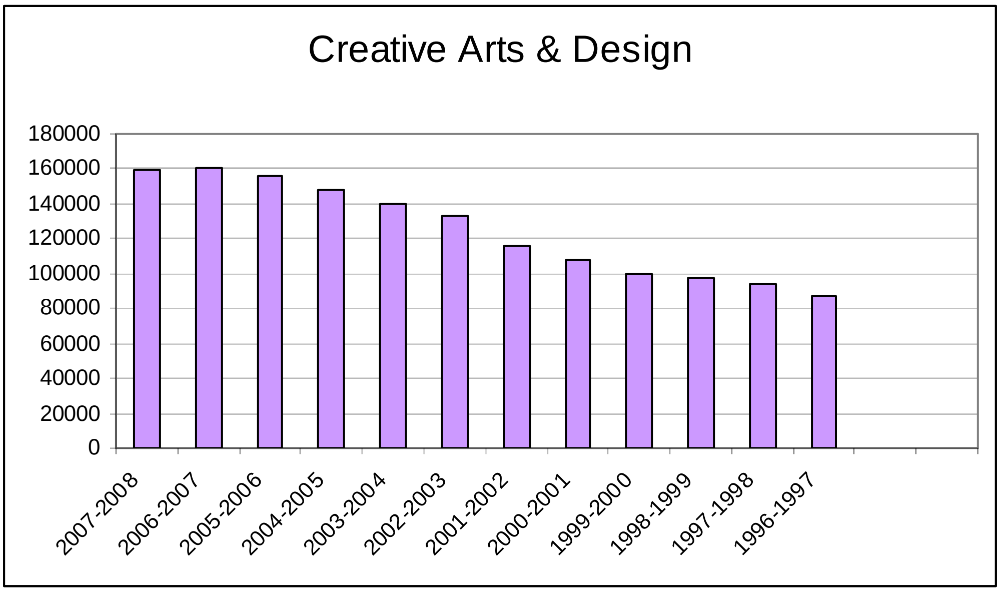

Figure 2.1: The diagram shows the number of students per year who enrolled for Creative Arts and Design subjects in higher education. The period 2008-1996 the number of students raised by 45%. The data derived from the Higher Education Statistics Agency (HESA, 2009)

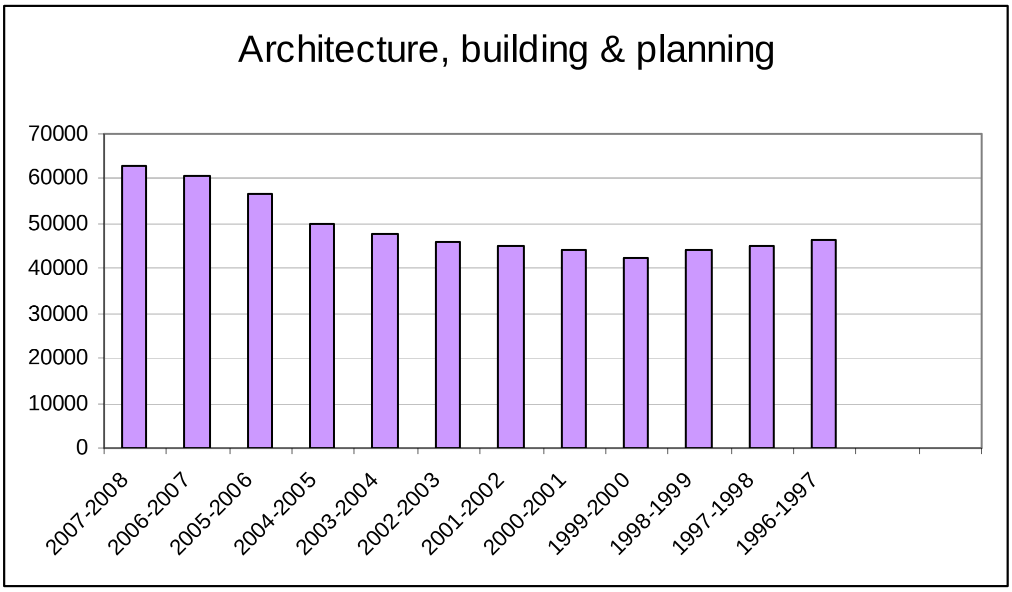

Figure 2.2: The diagram shows the number of students per year who has enrolled for Architecture, Building and Planning subjects in higher education. The period 2008-1996 the number of students raised by 23%. The data derived from the Higher Education Statistics Agency (HESA, 2009)

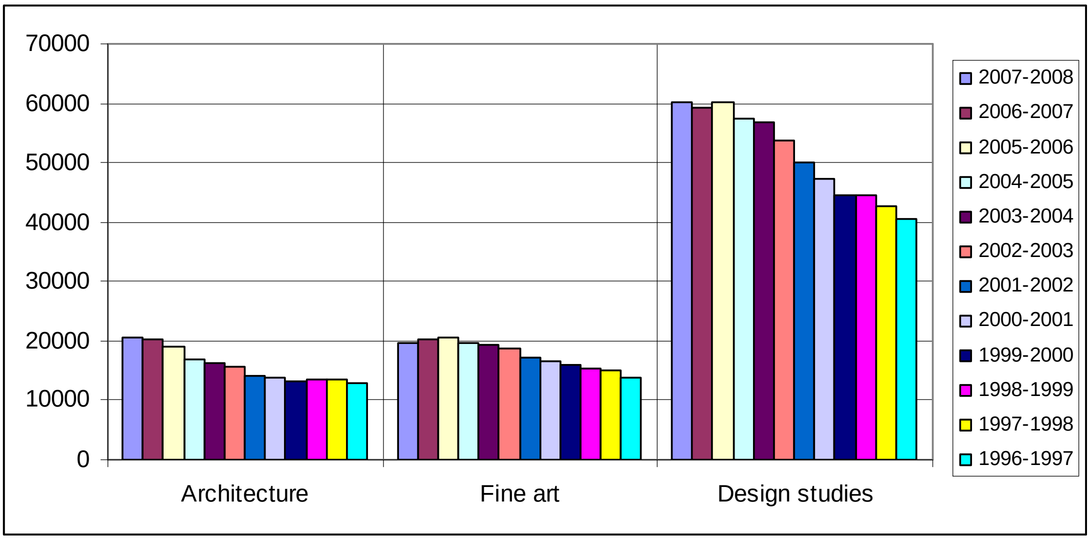

Figure 2.3: The diagram shows the number of students per year (2008-1996) who has enrolled for Architecture, Fine Art and Design Studies in particular. The data derived from the Higher Education Statistics Agency (HESA, 2009)

Other reasons that contributed to the raise of student numbers include: the widening participation agenda[3], the merging of the polytechnics and traditional universities (c. 1992) and the cuts in government funding. Many degree courses had to increase student numbers in recent years to compensate for cuts in government funding, and the resultant staff / student ratio and the lack of physical studio space have necessitated changes in the learning and teaching methods. The traditional studio environment cannot always accommodate the

[3] *Widening participation* refers specifically to recent government policy for improving access and widening adult participation in education.

increased number of students resulting in changes in the role of traditional subject-specific courses leading to more unitised and modular types of courses (Marsden, 2002, p. 299). Some subjects may be only provided through lectures without practical workshops – this approach is not in line with the hands-on, project-based philosophy of the discipline.

Baines (2004), who teaches the BA Graphic Design at Saint Martins College of Art and Design in London, stressed that *'the notion of studio teaching hardly exists, now that the Course has moved from "individual work desk", to "hot desk", to "no desk", to "virtual desk"*. Surprisingly, the course has 520 1st year students alone! Although this number may seem extreme, it reflects the issues that have risen from the socio-economic changes. He stated that *'traditional Art and Design learning environments are stretched to veneer and scholarship is reduced to acts of teaching performed at speed, whilst students backpack their way through the curriculum'* and he argues that there is a pressing need to utilise the potentials of digital learning technologies. This, however, has not been the strategy of all Art and Design institutions as some have chosen to preserve the traditional *atelier* method of studio-based learning by keeping a satisfactory staff / student ration that allows for effective tutoring sessions and sufficient face-to-face contact time. Hence the learning experience varies according to which Art or Design discipline(s), and in which institution, students have chosen to study (QAA, 2008, p. 2)

In brief, Art and Design education is facing significant issues: the need to attract and maintain student numbers balanced by an equally important requirement to preserve and improve the quality of learning and teaching in the face of growing pressure on staff time and resources (Sclater, 2006). On the other hand, the advances in technology and in particular the development of virtual learning applications and 3D virtual environments have opened new opportunities for Art and Design educators. The appropriate use of such media could resolve some of these problems. Educational technology has been slowly but progressively introduced over many years in most other academic disciplines. Still, some art and design tutors are doubtful about how most practice-based subjects could be learnt and taught via a virtual learning environment as opposed to face-to-face tutorials and hands-on experience. There is nonetheless a paucity of published research on educational technology applications in Art and Design education. The field that is better represented in this sector is Architecture[4]. The investigations concerning the pedagogical use of new technologies have been mainly exploratory. Only a few studies have conducted a formal evaluation of the educational effectiveness of the systems and have reported on outcomes. The general consensus is that a 'blended learning' technique could offer better results than an entirely

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[4] Architecture is often offered by universities and not Art and Design schools therefore different conditions and principles apply with regards to funding, facilities, technical support and attitude towards publishing research outcomes.

virtual learning approach. A brief review of the most commonly used educational technologies used in Art and Design is offered in Chapter 3.

9. Summary

The purpose of this chapter was to draw a picture of current Art and Design higher education. It discussed the studio-based learning and project-based learning methods applied in this area and presented the educational theories that are innate in this approach to learning and teaching. It then raised the impact that the socio-economic trends and changes had on the studio-based courses. The increase in student numbers, the ongoing pressures on teaching staff and lack of resources have resulted in an immediate need to explore other learning and teaching methods based on digital technologies.

This research reported in this thesis identified and analysed three educational problems and for each it has developed and evaluated a proposed learning activity based on 3D visualisation technology. The cause of the first educational problem (colour theory) is partly attributed to the current changes described above, whereas the other two problems (the scale of the interior designs) existed well before the changes occurred. The 3D technology used and tested in the three studies was identified as the most appropriate to resolve the particular educational problems.

Chapter 3

Educational Technology in Art and Design

How this chapter fits in the thesis

This chapter provides an overview of the different technologies used for learning and teaching in Art and Design higher education as a background to the use of technology in the studies carried out in this thesis. In particular, emphasis is given to the employment of 3D visualisation technology for educational purposes and not for designing and creating digital artefacts and spaces. Given that there is a paucity of literature on the development, implementation and evaluation of such technologies in Art and Design education, the chapter also draws from research conducted in other academic disciplines and discusses the pedagogical potential of 3D virtual environments. Some technical terms and features related to 3D virtual environments and VR technology are defined and described. The chapter concludes with a discussion on current trends and issues in the field of educational technology research.

1. Educational Technology in Art and Design

This section attempts to provide an overview of the different types of technology that are employed for learning and teaching in Art and Design higher education. This area is, however, still fairly unexplored. Only a limited number of studies were found that report on the implementation of the technology in existing curricula and on evaluations of its effects on learning outcomes and students' experiences. While educators and researchers in other disciplines have, for a number of years, been investigating the potential of technology for supporting learning and teaching processes (e.g. science, art and humanities, social sciences, medicine, etc.), in Art and Design there seems to be a general resistance and reluctance. Most educators argue that practice-based subjects require face-to-face communication and hands-on experience hence they are doubtful as to whether technology can replicate studio-based learning and teaching.

Most reports on educational technology in this discipline seem to focus on online Virtual Learning Environments (VLEs). In recent years, there has been a sudden spark of interest in investigating the potential of VLEs in this area. This can be primarily attributed to recent changes in educational agendas discussed in Chapter 2, section 7. The increased student numbers in recent years and the call for more autonomous, remote and flexible learning environments urged educators to explore the use of VLEs.

Moreover, after reviewing the literature on educational technology in Art and Design, it became evident that there are even fewer studies that evaluate the educational potential of other types of computer applications, such as shared 3D virtual worlds and 3D Virtual Environments (VEs). Given that this research set out to explore the educational potential of 3D visualisation technology, the lack of relevant literature means there is no established tradition of research to use as reference and the comparison of research findings is not always possible. Therefore, the review of educational technologies is extended beyond the discipline of Art and Design.

Some of the most commonly used types of educational technology are described below. Note that this chapter is not reviewing digital technologies that are used for designing and creating art and / or designs. There are a number of research projects related to that subject, but this thesis is concerned with educational applications. Moreover, as this research is placed mostly within the field of Art and Design education and not Computer Science, the technological features of each type of technology are not described here in detail. A more analytical account is offered only for the technologies used in the studies conducted as part of this research.

1.1 Virtual Learning Environments (VLEs)

The term VLE has been defined by the Joint Information Systems Committee (JISC) in the UK as a system that provides access to *'online interactions of various kinds which take place between learners and tutors'*. A number of commercial VLEs are available in the market; a few are open source. According to a survey that investigated the use of e-learning in Art, Design and Media higher education in the UK 42% of the respondents used Blackboard, 26% used WebCT whereas 26% reported no experience of using a VLE (Cheri et al. 2007, p 13). It appears that Blackboard is currently the university standard for course management, advanced teaching tools and building an online community on and off campus.

However, some educators argue that VLEs have drawbacks in terms of flexibility and usability (Hernandez & Samuels, 2006, p. 720). Many VLEs are based on proprietary software solutions, and meet generic, assumed needs which vary in their applicability to different disciplines and contexts. Staff and students have expressed concerns about the usefulness and suitability of Blackboard in Art and Design as they felt that the interface design did not provide a user-friendly and aesthetically pleasing virtual environment. Moreover, they believed that it is not the most suitable medium to support online communication and collaboration. For these reasons many VLEs are being used mainly for administration purposes resembling digital 'file cabinets' storing the handouts, course documentation, forms, announcements, etc.

Courses that deal with digital media (e.g. graphic design, multimedia, 3D animation, etc) seem to have been more successful in adapting to online delivery methods, whereas non-digital subjects (e.g. painting, ceramics, textiles, jewellery, etc) still face numerous challenges making staff and students sceptical about using VLEs. The belief that the studio-based learning and teaching philosophy cannot be easily replicated online is predominant. The overall message coming from this discipline is that most VLE systems available are not suited for Art and Design staff and students (Fisher, 2006, p 505). The visual nature of the discipline requires systems that emphasise the collaborative, visual nature of the practice and customised interfaces that reflect the studio-based learning (Malins et al. 2003; Sclater, 2006)

Although little has been reported on the effectiveness of readily available VLEs for learning and teaching practice-based subjects, there have been some efforts to create custom VLEs to suit the needs of Art and Design education. For example, a research group from Gray's School of Art in Scotland developed GraysNet (Malins et al. 2003). This VLE, created with art and design students in mind, supports collaborative modes of working online. More research is needed in order to identify best practice and thus overcome the current limitations of commercial VLEs. Most Art and Design institutions have adopted a blended learning approach, which means that some subjects are taught in the studio, whereas those suitable for online delivery are offered via the VLE.

1.2 Specialist software packages

Art and Design institutions would – depending on the course context – offer training in one or more specialist software that are commonly used in professional practice (e.g. Adobe Photoshop, Flash, Illustrator, VectorWorks, etc). Although this type of technology may be used daily by students, it is not considered 'educational'. These software packages are considered as 'tools' for designing, creating, making, etc., similar to what a paint brush would be to a painter or a chisel to a sculptor. As Cheri et al. (2007, p.17) stated in their report '*we have to be circumspect in equating the use of specialist technologies, however relevant they may appear to disciplinary learning outcomes, with "e-learning'"*. However, a few software packages, such as 3D modelling and CAD software, offer the ability to run simulations of phenomena, which allow students to observe and understand real-life processes. These are discussed in section 1.4.

1.3 Interactive Multimedia Applications

In the beginning of the 1990's the technologies of HTML (HyperText Markup Language), VRML (Virtual Reality Modelling Language) and Java provided the opportunity to present information to students in multiple media formats. HTML can be used to create the 2D elements (e.g. text and 2D graphics) while VRML provides a 3D multisensory experience, and Java is used to control behaviours between the 2D and 3D elements, and the interactions that the user performs. VRML enables 3D models to be viewed online using any browser; hence it could be used as a medium for public exhibition of work.

Today, the advances in software and hardware technology have eased the creation of interactive audio-visual applications, web-based or media-based (e.g. CD, DVD). There is a range of different multimedia authoring tools available on the market that do not require programming knowledge. For example, the most known software for this purpose is Adobe's Director, which is used for creating interactive games, demos, prototypes, simulations and e-learning courses.

A number of interactive 2D and 3D learning applications can be found on the internet. Although most are targeting younger learners, there are some that provide university level content. The majority of such learning applications often deal with science topics; the *Exploratories Project*[4] developed at Brown University, USA, is one such example. The interactive explanatory applications cover various topics including colour theory.

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[4] http://www.cs.brown.edu/exploratories/home.html

The ability to create and explore 3D objects and environments online presents many interesting opportunities for Art and Design education, especially in courses that deal with three-dimensional forms (Ashdown, 1996). A first example of the use of this technology for Art and Design is *NVRCAD* (Networked Virtual Reality Centres for Art & Design)[5]. This was a project that aimed to provide resources and support for higher education students and staff in Art, Design and the Performing Arts. It concentrated on digital technologies that involve three-dimensional work and its aim was to bridge the gap between practicing artists and designers, and the sometimes complex technologies involved.

In 2001, an interactive multimedia application called *SeeingDrawing*[6] was developed by the London Institute, Falmouth College of Art, Ravensbourne College of Design and Communication and the University of Ulster (Rowsell, 2002). The result of this collaboration was a DVD which aimed to develop visual literacy in students through computer-based technology. This application can be integrated into the teaching and learning in a variety of educational contexts. It includes images, basic training guides for computer applications such as 3D graphics, and projects which students can use to practice their drawing skills.

Glaze is another example of a multimedia application developed for Art and Design education, for ceramics courses in particular. Glaze's aim was to support self-directed learning by allowing students to explore and experiment with a range of glaze effects without the need for teaching staff to be constantly at hand. In addition, the reduced need for test firings entails greater efficiency for the ceramic studio and reductions in kiln and material costs (Fiddis & McConville, 2005). An idea to develop a similar multimedia application in order to teach textile students the knitting process was discussed by the teaching staff at University of Manchester, UK (Sayer, 2005). The tutors envisaged the potential of delivering some of the course's content through such an application as they could incorporate course content, film clips, animations as well as links to external sources to help students understand the knitting design process.

The projects described above offer examples of how this type of technology can be applied as part of the curriculum in Art and Design. A limited number of publications have appeared about such learning applications for Art and Design subjects, but no evidence of formal educational evaluation or learning outcomes could be found. The first study presented in this thesis proposed this type of technology for teaching basic concepts of Colour Theory. The main focus of the study though was not to develop the interface of the

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[5] The NVRCAD Project was active from 1996 - 1999 and involved activities at three centres: Coventry University, University of Plymouth and University of Teeside.
http://www.cs.waikato.ac.nz/oldcontent/cbeardon/nvrcad/index.html

[6] http://www.arts.ac.uk/itrdu/projects_seeing_drawing.htm

application but to design and evaluate the effectiveness of an innovative learning and teaching method. This is described in detail in Chapter 4.

1.4 3D Simulations

Simulations have been used for many years in science education. They offer the opportunity to simulate processes and abstract concepts that are not possible to experience in the real world due to scale, inaccessibility, safety, etc. Although there seems to be a plethora of simulations developed for physics, chemistry, biology, medicine, etc, this type of technology is not widespread in Art and Design education. Nevertheless, the following examples show the potential that this technology could have for learning and teaching particular subjects in Art and Design.

In Fashion and Textiles design, some advanced 3D modelling software packages can be used to design, construct and simulate cloth/clothing accurately (Taylor et al. 2003). In Architecture, the study of lighting inside building structures can be time-consuming and expensive if carried out with traditional visualisation methods. The use of computerised tools such as 3D, CAD and lighting design programmes, offer a solution to this problem. Useful information about daylight and artificial light effects can be generated and manipulated quickly and accurately; this is not normally possible with both studio and laboratory based tools (Hanna & Porter, 2005). Lighting programmes can import files generated by CAD programmes, if not already incorporated inside them (e.g. Accurender and SiView are offered within AutoCAD, therefore lighting design and performance can be analysed and assessed immediately). In addition, they can be linked to thermal analysis programmes so that the impact of design decisions regarding lighting, such as window size and position, on heat gain/loss can be assessed. Others have performed simulations using 3D modelling software (Maya) for cross building ventilation (Mokhtar & Khan, 2004). Such simulations are important for the education of novice architects.

1.5 Social 3D Worlds

The use of social 3D worlds such as *Second Life*[7] and *Active Worlds*[8] has been the latest trend in educational technology. These are online 3D virtual worlds created and populated by their users. These computer simulated environments are known as 'social' or 'shared' by virtue of being located on the internet, thus enabling any number of users, from many remote locations to use them simultaneously. The users are represented by avatars that can move

[7] Second Life is the most popular 3-D virtual world today. Since opening to the public in 2003, it has grown explosively and today is inhabited by millions of Residents from around the globe. (http://secondlife.com/)

[8] http://www.activeworlds.com/

around, perform actions, interact with other avatars and with the 3D environment. The concept of online social virtual worlds started around the mid 90's. The first worlds were text-based where all interactions happened by inserting text; these were known as MUDs (Multi-User Domains). Later, the proliferation of computer graphics technology made the integration of 2D graphics and 3D models possible inside the worlds. Older versions of 3D worlds were not so graphically rich, therefore they did not appeal to visual disciplines. However, the latest versions of these worlds seem to have attracted the interest of some Art and Design educators, both in terms of the satisfactory visual outcome and the social aspect.

A number of higher education institutions have created virtual universities in Second Life. According to a report that reviewed the participation of UK higher and further education in Second Life, some Art and Design schools were present in the world: Goldsmiths, University of London; Leeds Metropolitan University; London College of Fashion; Leeds College of Art and Design and School of Arts and New Media, University of Hull (Kirriemuir, 2007, pp. 6-7). The 3D world has been used to hold virtual degree shows and exhibitions (replicating real student shows) and to have online meetings between staff and students (especially with learners who might not be located on-campus). Some 3D animation and computer game design courses have used these worlds to upload and test 3D models they have created as part of the course. This provides them with a way to share their work and get feedback from other users. Gaimster (2007) explores the potential of Second Life as a vehicle for fashion education; however, she argues that although such shared virtual environments offer opportunities for engaging student-centred activities they require careful planning and more empirical research with regards to the educational effectiveness (Gaimster, 2008).

1.6 3D Virtual Environments

What is a 3D Virtual Environment?

The term '3D Virtual Environment' is widely used but there is no consensus on its definition. The term is ambiguous in that it can be defined as a virtual world or as a world presented via a particular VR hardware configuration. The term is defined in this thesis as a computer-generated, graphically-rich 3D world inside which the user is immersed and can perform actions in real time (e.g. interact with virtual 3D objects and other avatars) regardless of the type and size of display used. The main characteristics of a 3D VE are as follows:

- The environment is based on 3D computer models;
- The environment additionally can be experienced in real-time. The user's view of the environment is rendered dynamically according to their current position in 3D

virtual space, that is, the user has the ability to move freely through the environment and their view is updated as they move (Dalgarno, 2002, p. 3);

- The user can explore the environment through an egocentric or exocentric viewpoint. In the field of human factors, the words *egocentric* and *exocentric* refer to whether the world is perceived from a personal (first-person) point of view (egocentric), or from an external (onlooker) point of view (exocentric or third-person viewpoint). In an egocentric scenario, the viewpoint changes as the user moves through a space, whereas if the world is seen from a stable point of view then that is an exocentric viewpoint (Sherman & Craig, 2003, p 296);
- The user is typically constrained to the ground (as in real-life) and can 'walk' around inside the model;
- Depending on the application and purpose of the VE various types of interaction with the surrounding virtual elements can be supported;
- Some environments include 3D audio; audio that appears to be emitted from a source at a particular location within the environment. The volume of sound played from each speaker depends on the position and orientation of the user within the environment (Dalgarno, 2002, p.3). This research has not used sound hence this technology will not be considered further.

In brief, the term VE is used in this thesis to refer to the 3D model/environment/world and not to the type of technology used to view it, experience it, touch it, etc.[9]

In essence, a 3D computer model when viewed through the modelling software is not considered as a VE. The user needs to rotate, pan and zoom in order to get different views of the model, which is not the same as exploring the model from the inside. Furthermore, a 3D model has no virtual substance; in the VE the ground, walls, objects, etc. have been programmed to behave as real objects (e.g. the user cannot go through a wall because of surface constraints). The most common method to convert a typical 3D model into a VE is to import it into a software package, usually known as VR authoring tool, in which all the above actions can be programmed. This was the process followed in this research.

Virtual Reality

A VE can be experienced using different types of technology. The term *Virtual Reality* is often used to describe both the VE and the technology used to experience it, thus causing confusion. In this thesis the term *VR system* refers to the hardware and software that is used

[9] Note that Social 3D worlds are also 3D VEs, but due to their special 'social' character they were placed in another category.

to enable a user to become immersed in the VE. The type of VR system employed determines the level of immersion in, and interaction with, the VE.

Categories of VR systems

There have been many categorisations of VR systems. Sherman & Craig (2003) classify them as *Visual, Aural, Haptic, Vestibular and other senses* displays. Only the first category has been explored in this research. In turn, they further divide the visual displays category into *Stationary, Head-based and Hand-held* displays (p. 116). Only the stationary displays category is relevant to this research[10]; it encompasses monitor-based VR, otherwise known as *desktop VR* or *fishtank VR,* and projection-based VR. The size of the displays employed for projection-based VR are much larger than computer monitors and they are usually rear-projections (the projector is placed behind the display surface) to avoid the users casting shadows on the screen. The main difference between the two categories is *immersion.*

Immersion

Sherman & Craig's definition of immersion is *'the sensation of being in an environment; can be a purely mental state or can be accomplished through physical means; physical immersion is a defining characteristic of VR'* (2003, p. 9). Inducing a sense of *physical immersion* involves manipulating human sensory systems (especially the visual system) to enable the suspension of disbelief that one is surrounded by a virtual world. *'The impression is that of being inside an artificial reality rather than looking through a computer monitor "window" into a synthetic environment: the equivalent of diving rather than riding in a glass-bottomed boat'* (Dede, 1995).

Originally, the term *Immersive Environment* was used to refer to certain types of advanced VR systems in which the user can be fully immersed into the 3D synthetic world. Systems such as the CAVE (Cruz-Neira et al. 1993) and Head-Mounted Displays have been designed to provide a fully immersive experience: the sense of being inside the VE rather than seeing it from outside (i.e. through a computer screen) (Figures 3.1a and 3.1e). These systems use stereoscopic vision to enhance the depth of field and head-tracking that offers the ability of peripheral, unrestricted viewpoints (Figure 3.1c). The VE is presented to the user in real-scale, in human-size proportions which creates the sense of immersion. However, immersion in a VE can be achieved without stereopsis. A large display can also create the illusion of immersion by filling the user's field of view. For instance, the IMAX screen, certain flight and car simulators, and some video game set-ups, follow this logic in order to immerse the users in the experience. These non-stereoscopic large display systems have been termed *Spatially Immersive Displays.*

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[10] The second category involves Head-Mounted Displays (HMD) while the third one utilises Palm VR.

Figure 3.1: (a) a CAVE system in which the user is fully immersed (b) a semi-immersive VR system (c) 3D shutter glasses for active stereo 3D (d) polarised glasses for passive stereo 3Dand (e) head-mounted display.

Apart from the type of technology used to induce physical immersion, the content and context of the VE can also influence the feeling of immersion. Sherman & Craig (2003, p. 384) argue that the *'definition of mental immersion is that the participant is engaged to the point of suspending disbelief in what they are experiencing'*. They also assert that '*particular confluence of factors can persuade the participant of the existence of the world. The first of these factors is that the world has to be personally meaningful'*[11]. This feeling is also called *Presence,* and may be generated irrespective of the type of technology used. People often experience presence in video games and 3D VEs viewed through typical computer screens. Here the content is more important whereas some researchers have emphasised the importance of audio (Jelfs & Whitelock, 2000). To summarise, the factors that make a VE immersive are:

- A display that offers stereoscopic view. This could be achieved with either passive or active stereo 3D glasses. This research tested both passive and active stereo displays.
- A display that covers all or a big proportion of a user's field of view (Spatially Immersive Display).

[11] In Studies 2 and 3 presented in this thesis the students explored their own 3D designs, hence the spaces were familiar to them and therefore meaningful.

- Personal control of the viewpoint in real-time. In animations and videos the viewpoint is predefined hence the user is only a passive observer.
- The user explores the VE from an egocentric point of view, in real-life scale.

The diagram in Figure 3.2 shows the different categories of VR systems as discussed above. The technical details of the systems are not provided in this section as they are analysed in Chapter 5, section 5.6 and Chapter 6, section 5.5. Further definitions of some technological terms can be found in the Glossary.

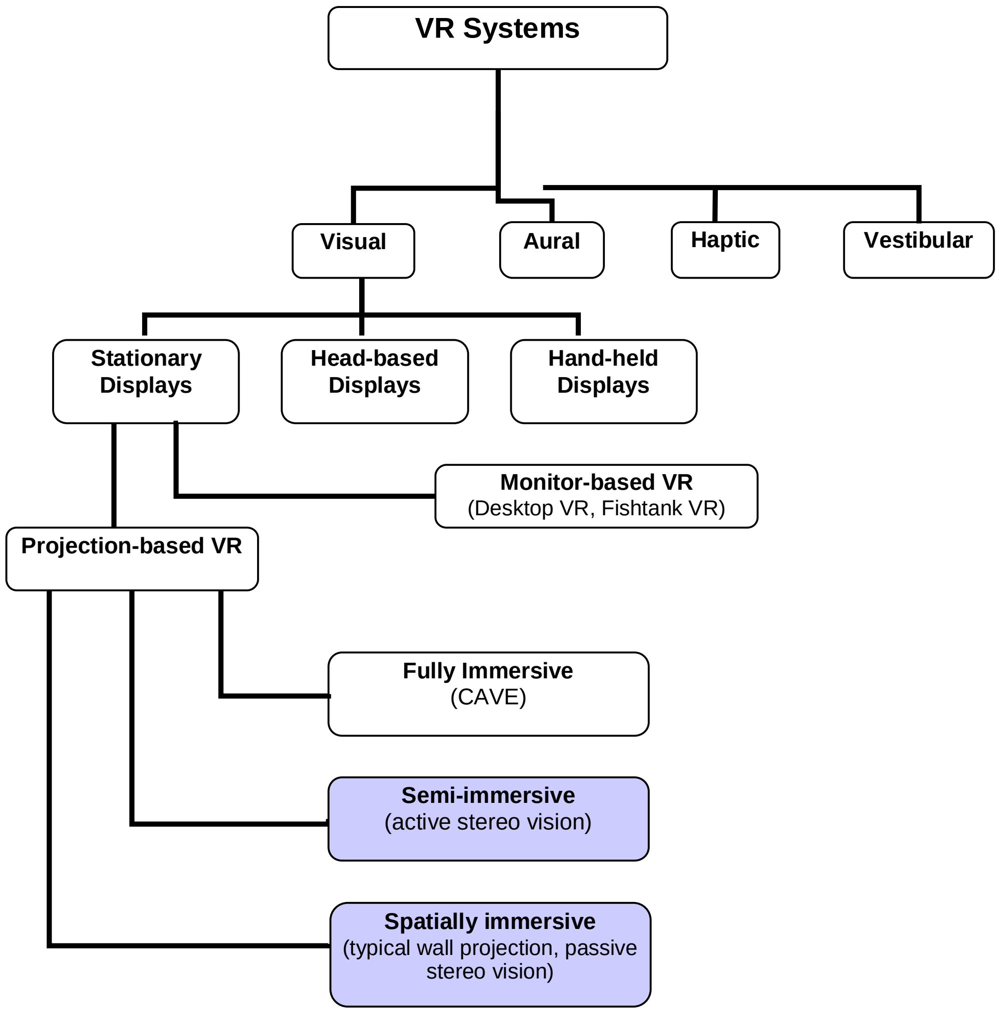

Figure 3.2: The diagram shows the different categories of VR systems. Studies 2 and 3 involved the categories highlighted in the diagram whereas Study 1 did not involve a VR system.

Desktop Virtual Environments

Even though they are known as Desktop VR these systems are not considered immersive. They can achieve a high level of mental immersion or presence depending on the application, but they are not evoking a sense of physical immersion. Desktop VR is an extension of interactive multimedia involving three-dimensional elements. This category embraces a plethora of different applications of which the boundaries are not clear and in fact quite often overlap. For instance, the social 3D worlds and 3D simulations presented previously fall into this category. This technology is often used by architecture, interior design and less for product design. Although most educational activities can be carried out using desktop VR there are some that require larger displays (e.g. for representing scale and spatial arrangements more accurately). Studies 2 and 3 identified that two of the educational problems that interior design education was facing could be addressed by using larger displays and so desktop VR was not relevant to them.

Immersive Virtual Environments

Even though this technology has been used for many years for training and educational purposes, only a few studies have in fact evaluated learning and teaching outcomes, and the impact on the learning experience. Most studies derive from the computer science sector and usually deal with technical aspects of the technology rather than an educational one. Investigations into the educational effectiveness of immersive VEs begun around 1993 although the findings of these early studies may not all hold today (because the recent advances in computer technology have improved the quality of 3D visuals and interaction considerably since these studies were conducted). This however, does not imply that earlier projects were not taken under consideration. On the contrary, most of them provided valuable data and points of reference for this research.

It appears that most of the studies on educational immersive VEs, were conducted between 1995-2000. This boom in VR research can be attributed to novelty effects, trends, funding opportunities, priorities, government agendas, etc. As such, one would assume that since 3D technology has improved and its cost has dropped significantly, a greater interest in evaluating the educational potential of VEs would arise. On the contrary, the number of research projects in this area seems to have reduced. This might be because the results of previous studies were not convincing. Some earlier publications outlined the negative aspects of previous VR systems (e.g. the graphics were not satisfactory, interaction was clunky and problematic, the size of the equipment was too big and the cost of hardware was too high), which discouraged most educators, developers and government funding bodies. The majority of these issues have now been resolved so perhaps it is now time to revisit the field to evaluate the potential of *current* VEs and VR systems on education.

Moreover, the majority of these earlier studies have evaluated *fully* immersive VR systems. These employ high-end equipment, such as CAVE systems, head-mounted displays, haptic technology and surround sound systems. Datagloves or datasuits allow the user to interact with the environment by tracking the user's motion and providing tactile feedback when he/she touches and manipulates the virtual objects in the simulated world. Ten years ago this technology was mostly used for research and training purposes due to the high cost of the equipment.

A CAVE (Cave Automatic Virtual Environment) is a room where images are projected on three walls and the floor. Users use head-tracked active stereo glasses and a wand to interact with the VE. CAVEs are particularly useful for virtual walk-throughs of cities, buildings, and archaeological sites; for evaluating products such as vehicles and furniture and even experiencing 3D art. Some of these systems support collaboration which means that users located at different sites can collaborate in real-time in a shared, simulated environment as if they were in the same room. This is likely to have important implications for some sectors, both academic and commercial.

Another form of an immersive VE is that of *Augmented Reality*. This is a combination of both the real, physical world and the artificial VE. By superimposing the virtual over the real object a more explicit and vivid experience could be created; this technique is often used for museum exhibits. Semi-immersive VR systems have been evaluated by a number of studies, but only a few have explored the educational potential of spatially immersive VEs and passive 3D stereo systems.

The value of immersive VEs for educational applications lies in its ability to immerse the learner in realistic, unique and/or abstract environments (Byrne, 1993). These virtual worlds allow the user to discover facts by interacting with virtual metaphors of abstract concepts and processes, to study the spatial attributes of a 3D space and to observe phenomena that cannot be encountered in the real world (van Dam et al. 2002). The following points form a list of the features of immersive VEs, as derived from a review of the literature:

1. *Ability to create new worlds and experiences*. Since the environments are created digitally, designers have the flexibility to build realistic worlds by imitating real life situations or constructing imaginary spaces. Taking control of time, scale, and physical laws provide learners with the ability to interact with virtual models of abstract concepts and processes, which would be impossible in the real world (Winn, 2002a; Dean et al. 2000; Salzman et al. 1996). They can also occupy objects as virtual bodies and observe the environment from different perspectives (Bricken, 1991). Usually, the range of phenomena students can interact with in a classroom are limited, whereas in a VE almost everything is feasible. Another important advantage of VEs is the fact that experiments can be performed safely. This allows students to make errors, from which they can learn important lessons (Winn, 2002a).

2. *Support experiential and constructivist learning.* VEs enable experiences, which are natural and personal, and generate direct, subjective and personal knowledge (Winn, 2002a;

Dede, 1995; Salzman et al. 1996; Dalgarno, 2001). They provide a context for both cognitive and affective learning by engaging the user in the learning process. When students interact directly with representations of abstract concepts, they can better understand these phenomena and create mental models that lead to longer retention of knowledge. This feature is important for Art and Design education where constructivist and learning-by-doing methods are applied daily in the discipline.

3. *Increased motivation and engagement*. Various studies have reported a rise of students' motivation in the learning task (Johnson et. al. 1998; Roussou & Gillingham, 1998; van Dam et al. 2002). Learning is more likely to occur when students are motivated and engaged by the learning environment (Laurillard, 1993).

4. *Support collaboration.* An immersive VE can be viewed by more than one student at the same time. On the contrary, a computer screen is designed for solitary operation hence it is not ideal for multiple viewers (Johnson et al. 1998; Jackson & Fagan, 2000). This feature can have a great potential for Art and Design education where collaborative work and peer interaction is important for learning and teaching. The immersive system allows students to explore a VE in groups and to view multiple perspectives of the world/object, which could encourage further discussion on the topic and increase motivation. Note that immersive VR systems that use head-mounted displays are not suitable for shared experiences, thus they would not be suitable for this discipline. On the contrary, semi-immersive VR and spatially immersive displays are seen as *'small cinema-like studios where audiences can share the feeling of being in a scene'* (Horne & Hamza, 2006).

Despite the positive attributes that immersive VEs have to offer, there follows an outline of some of the drawbacks as identified by other researchers. These have been taken into account while designing the VEs for this research.

- Learners are concentrating more in completing the task than learning. They seem to be more interested in the medium than the content (Sánchez et al. 1997). Confidence in using the interface does not necessarily signify understanding of the subject matter (Roussou & Gillingham, 1998).

- Interface usability and technical issues can be significant obstacles for learning to occur. Students need to learn the interface before completing the tasks and quite often getting familiar with the interface can take longer than expected (Johnson et al. 1998; Sánchez et al. 1997).

- VEs are not suitable for teaching facts (basic declarative knowledge) (Winn, 2002a).

- VEs are not good substitutes for real experiences especially when interaction with the real processes is feasible. They are ideal for helping students understand things that they cannot experience in the real world (Winn, 2002a).

Most studies that evaluated the educational potential of immersive VEs were primarily developed for learning and teaching science subjects to primary and high school pupils. Some earlier studies that do not fall into the Art and Design discipline are mentioned here as they provide valuable data for this research. Youngblut (1998, p. 29), in her review of educational immersive VEs that included and described over 70 educational applications, all created between 1994-1998, reported that the '*range of educational subjects covered is quite broad, showing a fairly equal split between the arts/humanities and sciences'*. For the arts/humanities, over one third of the applications addressed ancient civilisations while for the sciences, the most popular subject was physics followed by environmental sciences. None of the projects mentioned in the report related to Art and Design education.

ScienceSpace is a collection of virtual worlds designed to aid students in mastering challenging concepts in science (Dede, 1995; Salzman et al. 1996). This project was developed in 1994 at the George Mason University, USA. *MaxwellWorld* was built to explain the concept of electrostatics and *PaulingWorld* enables the study of molecular structures. All the environments were tested and evaluated documenting interesting results about the educational effectiveness of immersive VEs. In 1998, the Electronic Visualisation Laboratory at the University of Illinois at Chicago developed *NICE*: an immersive multi-user learning environment for exploring complex ecological interrelationships (Johnson et al. 1998; Roussou & Gillingham, 1998). The users can create their own virtual gardens, and by controlling weather conditions and time, they are able to observe the natural procedures. This study used a CAVE system. The findings indicated a rise in motivation and engagement and positive learning outcomes even though hardware issues created fundamental obstacles (Johnson et al. 1998; Roussou & Gillingham, 1998). The same research lab created the *Round Earth Project* in order to transform younger children's mental model of the shape of the earth (Johnson et al. 1999).

In 2001 the Human Interface Technology Lab at the University of Washington, Seattle, designed *Virtual Puget Sound* learning environment to simulate the processes of the ocean such as tides, currents and salinity (Winn, 2002a). The researchers tested and compared a desktop and an immersive version (HMD) of the VE. Their findings revealed that 3D VEs can help students construct new knowledge and experience things that are not otherwise accessible or feasible in the real world. The study also identified some drawbacks relating to interface and usability issues, and side effects such as simulator and motion sickness, as well as eyestrain. This research centre also created *Global Change World*; this study gave more emphasis on collaboration between learners (Jackson & Fagan, 2000).

A research group at the University of California in San Diego created the *Virtual Explorer* environment: an interactive simulation of a voyage through the human immune system (Dean et al. 2000). Students were able to interactively explore the immune system, at both the cellular and molecular scales. The *Virtual Gorilla Modelling Project* (Hay et al. 2000) is a HMD-based VE designed to facilitate deeper understanding of gorilla behaviours and social interactions. A more recent study, the *Virtual Playground*, allows children to design and build their own virtual playground while solving mathematical fraction problems (Roussou & Slater, 2005). The *Magic Cottage* is an interactive immersive VE that allows pupils to explore a 3D fairytale world in groups (Patera et al. 2008); this was developed to stimulate motivation and creativity in imaginative writing at primary school level.

From the above mentioned studies it is evident that the pedagogical effectiveness of immersive VEs has been evaluated on a range of different subject areas and education levels. Nevertheless, publications on similar investigations for Art and Design subjects are scarce; the majority of them emerge from Architecture[12] and a small number come from Product Design. Studies on VR technology and Art and Design rarely report on educational objectives and evaluations. Most often these concern the use of the technology for creating art by immersing the public in the 'work'. Others refer to research that is conducted to develop 'design tools' that employ VR technology in order to assist designers during the creative process. Although these even though they involve students in the evaluation stage, are often only meant to be used by professionals. In other cases, some institutions offer a module on VR technology[13].

While a number of architecture tutors report that their students have been using various forms of VR systems as part of the course, only a few have carried out an educational evaluation[14]. The implementation of immersive VEs in Architecture and Interior Design would seem a natural application in terms of offering the students the opportunity to become immersed in the 3D designs as opposed to viewing them on a computer monitor. Still, *'creating an interactive learning environment is not sufficient to bring about learning'* (Winn, 2002b, p. 346). More research is required in order to explore the advantages and drawbacks of incorporating this type of technology in to existing learning and teaching curricula.

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[12] To reiterate, Architecture is a course that can be situated between the discipline of Art and Design and Engineering. The same can be argued for Product Design.

[13] For example, the School of the Art Institute of Chicago offers a course on 'Immersive Environments: Art in Virtual Reality'. The topics covered include 3D modelling, sound, and programming for VEs using a CAVE. The aim of this course is to teach students how to make art in virtual reality.

[14] The studies that are relevant to the topics examined in this thesis are offered in Chapters 5 and 6.

2. Educational Technology: Trends and Issues

The field of educational technology is rich with '*speculation about dramatic improvements in learning'* that will be accomplished through innovative applications of new technologies (Spector, 2002), yet, there is little empirical research being conducted with regard to the effects on learning and teaching. There is little evidence on which to base a judgment with regard to the advantages of using specific kinds of technology in various educational settings. A number of researchers have expressed concerns about a noticeable technology-driven approach to educational technology research.

Interestingly, the design of educational systems and learning environments has not become simpler on account of advances in technology; rather, it has become significantly more difficult. A plethora of different technologies is now available to the developers, who often get enthused and interested to test a new piece of software or hardware without having set a learning objective first. Spector (2002) argues that ignoring learning objectives is not likely to lead to improvements in learning and teaching. Educational objectives determine to a great extent how to design effective support for learning to take place. Most often the focus of educational research is the technical aspects and characteristics of the technology whereas particular emphasis should be given to the pedagogic models and processes that the technology has to serve and to the contexts within which learners engage with it (Kirkwood & Price, 2005, p. 270). Recently, many educational researchers seem to explicitly or implicitly discredit this and other fundamental principles of educational theories.

Winn (1997) states that often educational technologists may be impressed by the enthusiasm with which learners engage with the technology (in particular immersive VR systems) and therefore it is easy to draw the wrong conclusions about its effects on learning. Inarguably, motivation and engagement contribute to learning, but other cognitive processes need to be triggered as well. He calls this '*the danger of advocacy*' and he prompts researchers to gather evidence about the relative effectiveness of the technology as well as to present objective evidence (p. 12).

Draper (1998) argues that the cases in which computer technology has shown definite educational benefits are those that have followed an approach where the educators have identified a weakness in the existing learning and teaching methods, and have analysed how technology could potentially resolve this problem. He also asserts that there are no generalisations about the success of educational technologies: what was good about the implementation of the technology on a particular subject area / discipline / institution may not be good for another. Studies that demonstrated successful employment of educational technology are those that first identified a limitation in the current delivery method. It is not rational to replace aspects of learning and teaching that already work well and are in most cases essential (Draper, 1998 p. 7). Some learning goals are effectively met with traditional and well-established methods; these should not be abandoned when embracing new technologies (Spector, 2002).

The following study provides an example of a technology-driven approach to educational research. Bucolo & Brereton (2004) conducted a study to compare the effectiveness of an immersive VR system on design review sessions of product design. They compared the traditional method (which uses physical 3D foam models of the products) to the immersive method (which uses 3D computer models). The student's feedback on the usefulness of the digital version was fairly negative. They encountered usability issues and problems in communicating aspects of the design. The students said that the traditional physical models were more intuitive to use within the context of a design review as they allow them to focus on the design discussion rather than diverting their attention to manipulating the 3D model in virtual space. This shows that there was no problem with the traditional method of conducting the design review sessions and the technology removed aspects that were important for this particular activity.

However, one student explained that a design could be reviewed more effectively if both methods were combined: *'Overall the VE is relatively quick to prepare and is a great way of presenting a design concept onscreen. However, more traditional methods such as physical 3D models have always been an excellent communication tool because it is something that communicates straight away design issues that may not be so obvious onscreen, such as the size of the product. I think a combination of physical 3d models together with computer-generated images such as those created in VR is ideal for presenting a design concept. This is because both elements offer something unique, which the other doesn't. So a combination of both traditional and new design tools such as a virtual environment would be ideal for a design presentation'* (Bucolo & Brereton, 2004).

Replacing entirely one form of delivery with another has seldom proven effective across a variety of settings (Spector, 2002). A blended learning approach can often offer more educational benefits. In Art and Design education in particular, educators strongly believe that the use of technology should remain supplementary to face-to-face contact. Experience has shown that the dynamic interactions created by both approaches can enrich the learning and teaching (Hernandez & Samuels, 2006, p. 726). Computer technology can generate new methods of learning and teaching, but it cannot ensure that the learning objectives are met. *'It is not technologies, but educational purposes and pedagogy, that must provide the lead, with students understanding not only how to work with the technology, but why it is of benefit for them to do so'* (Kirkwood & Price, 2005, p. 258).

In brief, the medium itself is not the most important factor in any educational programme. *'What really matters is how it is creatively exploited and constructively aligned. The educational benefits that students perceive as gains from using technology are more significant than the intrinsic characteristics of any particular medium'* (Kirkwood & Price, 2005, p. 272). Furthermore it is important that computer scientists, educationalists and content experts lead the design process conjointly. The process of developing an educational application is often unbalanced as each of these groups has its *'own respective competences they neither overlap nor cover the entire complexity of the applications'* (Mellet-d'Huart, 2006, p. 254)

3. Summary

This chapter attempted to set the wider theoretical and contextual framework for the empirical investigations presented in the subsequent chapters. It presented the various types of computer applications that are most often encountered in Art and Design education. It provided more information on the types of technology that have been used in the studies and discussed how these have been applied in other disciplines as well as in Art and Design. Current approaches to the implementation of educational technology in academic curricula have been also raised in this chapter.

By taking in to account earlier successful educational technology studies and current trends and issues in the field, this research followed a learning event-centred and not a technology-centred approach. This thesis begun by identifying an educational problem: the way Colour Theory is taught. Then, after an initial investigation on how this problem could be resolved, the research set out to explore the potential of 3D visualisation technology for learning and teaching the particular topic. The first study identified other educational problems thus providing the rationale to conduct two further studies. The technology is viewed as tool that can be used (in some cases) to enhance current learning and teaching methods and not as the focal point of the leaning activity.

Chapter 4

Study 1: Colour Theory

How this study fits in the thesis

This chapter presents the first of the three studies. This study designed and tested a 3D interactive learning activity for learning and teaching basic concepts of colour theory such as hue, saturation, value, colour systems and so on. Current learning and teaching methods on colour theory were identified as inadequate hence a 3D interactive learning activity based on constructivism theory and Socratic questioning was proposed as the potential solution to the existing educational problem. This study aimed to evaluate the effectiveness of a tutoring method that uses 3D visualisation technology on the topic of colour theory.

1. The Topic: Colour Theory

The rationale for choosing the topic of *Colour Theory* derived from my personal experience of a colour course that was part of my undergraduate degree. Colour theory was one of the important subjects of the *Technology of Graphic Arts*[15] degree, at the Technological Institute of Athens, Greece. The course was offered during the 2nd semester (the academic year was divided into two six-month semesters) and it lasted for one semester, and involved two weekly modules: a lecture and a workshop. The lecture was conducted via a traditional didactic lecture which dealt mainly with additive colour (light theory), optics and colour temperature, colourimetry principles, colour systems used by the printing and ink industries. Visual aids were limited during the instruction, and the handouts were printed in black and white, making it even harder for learners to build the connections between the text, the theory under investigation and the visual recollection of hues only from reading their symbolic representation e.g. red or R, blue or B.

On the other hand, the workshop was delivered by a different tutor and involved practical exercises such as creating colour wheels, scales of shades and tints of a hue and compositions using cool and warm colours. The practical part of the course had no immediate connection to the theory presented during the lecture as it dealt mainly with pigments hence with subtractive colour rather than additive. So, while the workshop provided an instant visual outcome of the theories applied and was thus enjoyable, comprehensible and easier for students to pass, the lecture involved written exams at the end of the semester that the majority of students were failing to pass. Enquiries regarding the appropriateness of course content and the teaching method began to arise since every year the number of students attending the exams for this course was increasing; for some learners it could have been their fifth attempt. As a result the department decided to aid the students by arranging an additional Saturday morning lecture instead of changing the teaching approach or attempting to align the content of the lecture and the workshop. This solution however did not improve the examination results.

I recall searching for relevant books on colour theory in an attempt to see coloured visual representations of the concepts or phenomena described in the course's handouts. Every discipline though (i.e. art, physics, chemistry, psychology) has a different approach with regard to the creation, use, application and interpretation of colour, therefore the quest to gain a deeper understanding of the lecture's content by gathering knowledge from other books on colour resulted in even more confusion. At the time (1997), educational material

[15] The course dealt with modern and traditional processes of printing and printmaking, image processing, professional scanning, desktop publishing, bookbinding and packaging design.

offered online was not as common since the connection speeds were considerably slower and the graphics and interactions were not as advanced as they are today. At the time, my main worry was to pass the course hence I did not analyse these problems further. It was only years later (2003), during my postgraduate degree in 3D animation, that it dawned on me that some of these concepts could have been explained more effectively with the use of three-dimensional representations. This idea also inspired the formation of the main research question of this doctoral study.

This investigation began with enquiring into how other colour courses were conducted in other higher education institutions and in other countries. Most departments seemed to encounter issues with the delivery of the colour course, while others had entirely removed the course from the curriculum. Indisputably, the interdisciplinary nature of colour makes its learning and teaching challenging given that it can be studied from various viewpoints including physics, optics, philosophy, art, chemistry, psychology, etc. The same colour principles may apply to all these areas but the relative importance of each may be different. In most cases even the language differs, let alone the methods and applications. Furthermore, colour theory involves many abstract concepts that are difficult to explain given that they do not have a visible or tangible form in the real world. Therefore its learning and teaching could benefit from the use of appropriately designed visual aids. The use of modern visualisation technology could significantly enhance the traditional lectures, workshops and handbooks, given that computers can produce a vast range of colours and three-dimensional graphics.

In essence, my own experience of a colour course and the apparent educational issues highlighted by similar courses, formed the rationale behind the selection of the topic of *Colour Theory* to conduct my first study. The review on past and current colour education and its inherent educational problems is provided in the subsequent section.

2. How is Colour Theory Taught?

Recent technological advances have contributed to the creation of products ranging from a vast chromatic variety of paints, from glowing and fluorescent to iridescent and metallic pigments. New materials are constantly being developed providing even more possibilities for creative colour / material designs. Computer technology can now produce millions of colours and television monitors and screens are emitting more colours than the eye can possibly process. This advance has affected many industries and increased the amount of colour stimuli people are exposed to every day and the variety of materials and tools they can use, therefore colour education is considered more essential than ever. However, instead of witnessing an enhancement and reinforcement of modern colour education by utilising the available resources, there is a noticeable lack of it, especially within Art and Design institutions. Willard (1998) describes this situation *'a dystopia of colour education in a utopia of colour experience'*.

A number of Art and Design educators and researchers have highlighted the lack of courses on colour even in programmes where it is important to students' subsequent professional practice e.g. painting, graphic design, textiles, interior design and architecture (Bergstrom, 2002). Janssens & Mikellides' (1998) cross-cultural study, even though it focused mostly on architecture, is one of very few investigations on the status of colour education in higher education. The authors investigated the knowledge of first and final year architectural students of three Swedish and two UK schools of architecture (a total of 448 students) on perceptual and psycho-physiological aspects of colour, colour nomenclature, existing myths and beliefs, and how colour is used in their everyday work in the studios. The findings showed a severe lack of knowledge about colour research in both countries. Most of the students complained about the lack of coverage of the subject area in lectures, seminars, or studio work, with very little theory and only few practical exercises.

2.1 Lack of Colour Education

This section examines the reasons that contributed to the lack of dedicated colour courses in Art and Design institutions worldwide.

Time and space

Research indicates that colour theory has been either integrated into other subjects or totally withdrawn from the curriculum of most art schools due to time scarcity (Bergstrom, 2002; Arnkil, 2005). Recent changes in the Art and Design curricula have affected the topic of colour among others that were traditionally taught in a studio environment. The increase of student numbers in some Art and Design courses has made studio-based instruction difficult to maintain (Smith, 2002), resulting in the shift of these subjects to less studio-based learning and teaching environments or to workshops running only for a limited period (e.g. one or two weeks usually during the first year), thus leaving the learners no time for experimentation and reflection. Janssens & Mikellides (1998) ascribed the students' low knowledge level with respect to colour research to the generally reported lack of time in the teaching schedules. According to this study, almost all the lecturers complained about shortage of both lectures and workshops on colour as a subject and this issue was also supported by most available architectural curricula examined.

Introduction of new subjects

Another reason for down-rating or excluding certain subjects from the curriculum is the introduction of newer subjects that emerged from the advances in technology and digital media. Nowadays, Art and Design schools offer many different courses ranging from fine art, ceramics, and textiles to interactive multimedia design and 3D animation. Therefore, the integration of modern subjects and technologies is necessary but the time may not be sufficient to include both new and past modules in the schedule, especially without altering their existing format. Often, changes have to be made to the content and context of traditional subject matters in order to adapt to the evolving requirements and needs of each course and of the times in general.

Colour education needs to be updated

Conversely, colour education has not notably evolved. For more than 40 years the majority of course assignments on colour in most Art and Design institutions have been based on Josef Albers' book *Interaction of Colour* originally published in 1963 (Albers, 2006). Undoubtedly, Albers' practical colour experiments were and still are valuable for developing a sense for colour and learning about the interrelations of colour as they address the important issue of 'perception' (Figure 4.1). They also avoid complicated scientific explanations and encourage experimentation. The aim of these exercises is to learn about colour through experience and a trial and error process. Practice comes before theory as a process of discovering the knowledge. Usually, Albers' students would attend intensive colour workshops that could last from one to two years. The duration of the course was important to reach a deeper understanding of colour and its effects.

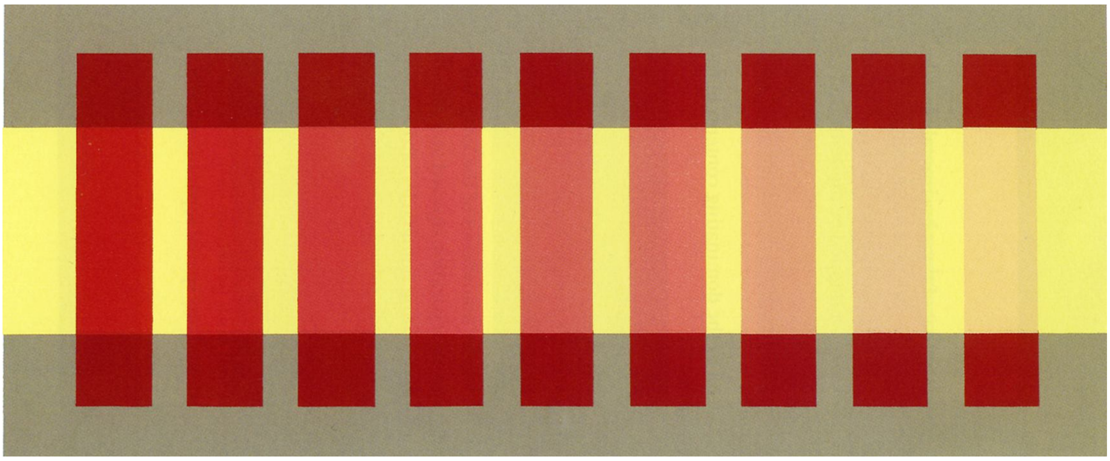

Figure 4.1: An example of Albers' colour exercises. This exercise aims to create the illusion of transparency and space through the graduation of the red hue.

Other tutors have chosen to follow Johannes Itten's approach to colour education which is very similar to Albers' (Albers and Itten were both Bauhaus scholars so they shared the same art education philosophy). His books *The Art of Colour* and *Design and Form*, published in 1961 and 1963 respectively, provide a description of the colour exercises as well as presenting the theories and laws behind the observed phenomena (Itten, 2002; Itten, 1975). Itten also reported on his experiences of teaching at the Bauhaus and argued that colour education is important for artists and designers.

However, as mentioned previously, presently, academic departments cannot afford to dedicate this amount of time, and occasionally space, to only one module. As a result, only a few of Albers' or Itten's exercises tend to be carried out in a rushed manner, which does not allow for a self-paced, exploratory acquisition of knowledge as originally intended. Furthermore, the theories and skills obtained from this sort of class are not all applicable to all courses. Exercises involving primarily two-dimensional geometric forms ignore more complicated three-dimensional forms and the interplay between colours, light and shadow, thus running the risk of *'perpetuating art-school colour theory as a specialist subject in itself and not obviously related, by the student or teacher to subsequent diverse artistic practice'* (Osborne, 2005). Roy Osborne argues that Albers' colour course may present *'something of a dead-end'* for students who wish to work with more complex forms and compositions or other media (Osborne, 2005).

For instance, the ability to create an accurate gradient scale of red using paints is of no use to a web designer for whom digital colour management would be more useful. Traditional colour exercises are valuable and important but they were developed more than 40 years ago, before the invention of digital media, hence the need to update current colour classes becomes more pressing in order to effectively correspond to new courses' requirements (Kim & Chung, 2005). Even the students who work with computers cannot see the purpose of the traditional colour mixing workshop as in the digital environment they 'click, drag and pick' a colour from a palette created by the RGB system (Red, Green and Blue) (Smedal & Jacobsen, 2005).

Furthermore, the colour exercises of Albers and Itten do not convey the effects of colour on emotions, mood and space ambience, and they do not deal with light, shadows and three-dimensional forms and environments. Shashi Caan (1995, p. 152) argues that: *'…the Bauhaus and its modernist legacy, has produced a fragmented rather than an integrated design education. The intellectual focus on the purity of line and form denies the potency of more emotive and sensual qualities offered by colours, textures and patterns.'*

Colour theory limits creativity

The belief that colour theory is mostly relevant to people who will become painters and that the rules of harmony could restrict students' creativity has partly influenced the decision to dismiss the course. This attitude towards colour theory courses seems to have affected the Art and Design discipline more than others. Surprisingly, non-artistic courses (e.g. computer science, psychology, physics, chemistry, etc.) provide at least one lecture on colour, a workshop when appropriate and various online learning resources (Henry et al. 2003; Schanda et al. 2002; Meier et al. 2004). However colour education should not only be about rules, harmonies and colour naming systems. Students could benefit from recent research on colour perception, psychology and neuroscience as their work could be informed by research findings and lead to conscious and confident decisions when selecting colours. A general approach to colour could benefit all Art and Design subjects, not only painting. But in order for this to happen, current colour courses need to be reconfigured to incorporate the new knowledge and broaden the scope of colour education.

2.2. A Review of Current Colour Courses

In order to discover how the various departments and Art and Design schools teach colour a small survey was conducted. This enquiry on how colour is taught began from the GSA, where this doctoral study was undertaken. A meeting was arranged with the tutors of the 1st year Design programme. When I visited the department I had a discussion with one of the lecturers regarding the colour exercises they assign to the students and I also had the opportunity to attend the assessment of the colour projects.

It was mentioned that the project briefs are changing constantly as the tutors were designing different practical exercises every year. That year (2003-2004), for example, the students had to complete five exercises. The first one was to choose colours that better correlated to pre-specified words (i.e. tropical, sugary, vintage, poisonous, etc.) then they had to mix these colours with others (black and white paints were not allowed) to get different tonalities. For the last task, the students were asked to choose two objects they had at home and recall their colour and afterwards recreate the attributes of the objects (colours, textures, patterns, etc). Figure 4.2 shows some the students' work.

That year, the students were assigned the tasks and were not offered a lecture on colour theory. The tutors' experience was that the theory lectures at the start of the course were not very exciting for the students hence they were inclined to focus more on the practical part. The scope of the course is to teach colour through a series of assignments that require creativity and observation. It is anticipated that through these exercises the students would be able to understand the basic aspects of colour theory even though these do not seem to be mentioned in any way.

I also attended a lecture on colour provided by the photography department, which followed a totally different approach to the one described above. Although the works of scientists, artists and theorists such as M.E. Chevreul (1786–1889), J.W. Goethe (1749-1832), F.V. Delacroix (1798-1863) and J.C. Maxwell (1831-1879) were mentioned, the course focused more on colour and meaning. The concepts discussed here were based on philosopher Ludwig Wittgenstein's book *Remarks on Colour* (Wittgenstein, 1978). The aim was to provide the learners with some conceptual critical tools to aid them to interpret and understand colour within photography.

Figure 4.2: The photos depict some of the students' works for the colour theory course at the GSA.

The other departments at GSA do not offer a dedicated course on colour as they have integrated it as a component of the students' assignments. It is assumed that students would use colour in their projects and therefore they would need to investigate its application, meaning, impact and so on. Usually any problems the students' work might have with regard to colour are only noticed at the last stage of the project if not at the final assessment of the work. The interior design tutors, for instance, commented that most students would postpone the colour treatment until the end of the project and therefore it might not be as thought-out and successful. If students applied colour from the start of the project and tutors gave them feedback at that stage then probably it would encourage students to study the topic more systematically and learn through a trial and error process.

After getting an insight into how colour is taught at GSA, the enquiry was extended to other institutions in the UK and worldwide. Most higher education Art and Design institutions' websites mention that Colour is a taught module (either stand-alone or integrated into another module) usually delivered during the first term or year of a course. However, the websites do not provide further information with regards to educational content, teaching methods or the duration of the course (e.g. hours per week). Another way to collect such information would be to contact the tutors of the colour course but it is exceptional if a name or any contact details is available via the website of an institution. Therefore, an in-depth investigation into this matter requires a formal survey, perhaps employing an online questionnaire, which was beyond the scope of this research. Hence this brief review of basic colour theory courses was conducted by employing mainly secondary research methods.

Often, a specialised course on colour may be offered by a higher education institution as a short course. For example, the University of the Arts London offers the following colour-related short courses: Introduction to *Colour Theory through Practice* (2 days), *Exploring Colour for Designers* (3 days), *Colour Communication for Graphic Design* (2 days), *Colour Theory into Practice for Interior Designers* (3 days) and *Colour Psychology* (5 days). The latter is conducted in collaboration with *Colour Affects*[16], a consultation company founded by Angela Wright, author of *The Beginner's Guide to Colour Psychology* (Wright, 1998). This company assists individuals and organisations to harness the profound psychological influence of colour on human response and behaviour. The Norwegian Colour Research Laboratory[17] at Gjøvik University College, Department of Computer Science and Media Technology, also offers a series of small workshops that cover various topics related to colour science and image processing. A list of institutions, which provide colour courses, either as short courses or taught modules, can be found at Prof. Jill Morton's website *Color Matters*[18] .

Given that publications related to colour education are rare, the most valuable source to gather information was the *International Colour Association (AIC)*[19] and *CREATE*[20] conferences which have a dedicated session to colour education. Informal discussions with colour educators and researchers at these meetings assisted in forming an image of the current state of colour

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[16] http://www.colour-affects.co.uk/. The company advises corporate clients on colours for branding, packaging, web, interiors and product design, and individuals on colours for personal growth, fashion, make-up and hair colouring and residential interiors.
[17] http://www.colorlab.no/education
[18] http://www.colormatters.com/des_studycolor.html
[19] http://www.aic-colour.org/
[20] http://www.create.uwe.ac.uk/

education in the various disciplines worldwide. Here I provide some examples of approaches to learning and teaching colour theory, not only drawn from the domain of Art and Design but also from other disciplines. The rationale for referencing work from other fields initially stems from the multi-disciplinary nature of colour and secondly from the view that current Art and Design educational methods could be informed by successful learning and teaching techniques applied in other disciplines. Note that the courses mentioned below refer to general colour theory or otherwise basic colour courses and not to specialised subject-specific colour use and application (i.e. textiles, ceramics, interior design, graphic design, etc.). Furthermore, since the investigation concentrated on tertiary education, courses or learning applications designed for adolescents have not been included.

It appears that most art schools either follow an entirely practice-based approach (based on Albers and Itten) or they do not offer a course on colour as an individual module. A plethora of books on colour theory and colour use in art and design have been published through the years. Educators can reference or draw inspiration from these in order to design their colour exercises. Most of these books include variations of Albers' and Itten's exercises as well as physiological, anthropological, philosophical, historical, psychological and sociological approaches to colour perception. Among others these include Birren Faber's and John Gage's books, Agoston's *Color Theory and its Application in Art and Design* (1987), Osborne's *Colour Influencing Form: a Colour Coursebook* (2004), de Grandis' *Theory and Use of Colour* (1986), Zelanski's and Fisher's *Colour* (1999) and Feirner's *Colour: how to use colour in art and design* (2000). A chronological bibliography on colour theory (from 360 BC to 2007) compiled by José Luis Caivano can be found at the website of the Colour Research Program at the School of Architecture, Design and Urbanism of Buenos Aires University[21].

Some of Albers' students have distinguish themselves in the field of colour education by developing and publishing their own approaches to teaching colour, extending the lessons of Itten and Albers by experimenting with colour, light and three-dimensional forms and exploring colour applications for computer graphics. The artist, author and educator Lois Swirnoff is one of those students. She has experimented with optical illusions involving the interaction of colour, form, light and shadow and the transformation of the relational colour objectives from two dimensions into three dimensions. Her book, *Dimensional Colour,* includes a number of three-dimensional colour experiments created with physical material (Swirnoff, 1989) (Figure 4.3). Her experiments have inspired many tutors of fine art, architecture and interior design. The next Chapter discusses colour courses which have been designed with architecture and interior design students in mind.

[21] http://www.fadu.uba.ar/sitios/sicyt/color/bib.htm

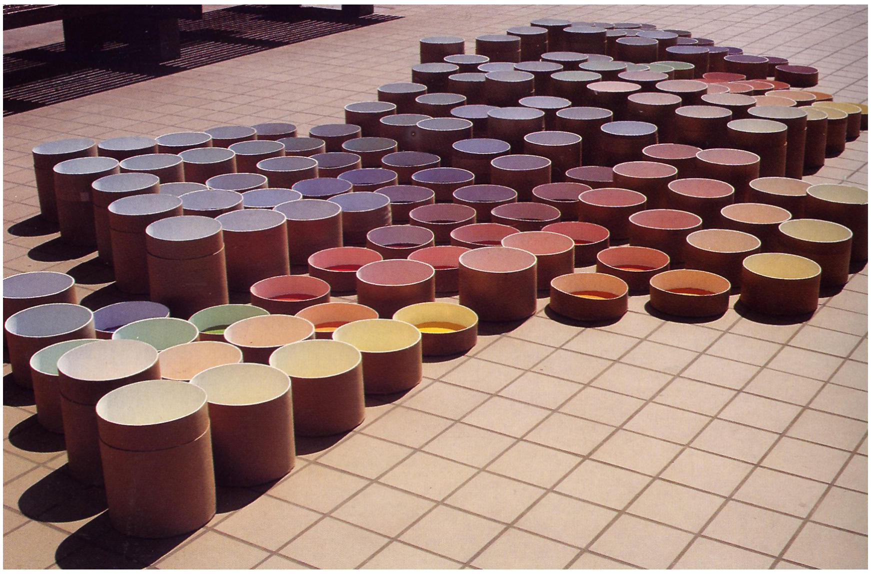

Figure 4.3: This experiment by Lois Swirnoff demonstrates the relationship between colour and saturation and daylight in the environment. Shifts in the angle of incidence of the sun during the course of the day significantly alter the perceived intensity of the individual hues (Swirnoff, 1989).

A tendency to digitise colour exercises and present them through on-line or media-based learning applications has become evident. Most tutors support the use of new media as the number of students in the studio is constantly increasing and this does not allow for a meaningful face-to-face interaction, not only with the tutor but often with peers. Hence the new media approach is seen as an opportunity to allow students to study the subject further in their own time, pace and place. Nevertheless, most of the media-based or web-based learning environments offer the theory as found in the textbooks and the existing known colour exercises have been converted to digital format without applying an appropriate educational theory. This behaviourist teaching approach does not foster experimentation, self-discovery and problem-solving learning opportunities, and in addition it does not maintain the students' interest (Bendito, 2005). The following examples of computer-based colour education have taken a step further as their design has been based on educational technology and/or their content and context has been successfully adapted for digital delivery.

Kwon & Kim (2002) in 2000, developed a web-based digital colour education system, which includes all course materials, a discussion room, and virtual communication between instructor and students. The design of this virtual learning environment was based on constructivist educational theory and aimed to supplement face-to-face teaching by providing a learner-centred environment. A case study was conducted at the Korea Advanced Institute of Science and Technology to evaluate the effectiveness of the application. Unfortunately the online learning environment, Hongik Digital Color[22], is only offered through the university's system and is in Korean.

[22] http://digitalcolor.cyworld.com

Garth Lewis (2004) at the Central St. Martins College of Art and Design, University of the Arts, London, delivers the colour course both in the studio and digitally. The *Virtual Colour Course* uses *Chromafile*[23]: a software that simulates paint colour mixing on screen (Carabott et al. 2002) (Figure 4.4). It is a new palette of paint-colour mixtures that adds to the existing options of RGB and CMYK colour; it can be used within Photoshop and other software applications. In 2002, the development of a project called *SeeingColour* was inspired from Lewis' colour course (Rowsell, 2002). This project aimed to provide a network-based basic colour course, with the objective of sensitising students to colour relationships through the provision of standard colour exercises from Albers' book. According to the author, the analogy with paper swatches and how they are used in collage, which formed the basis for the software tools of *SeeingColour*, resulted in methods of working that are quick, easy to use and independent of accurate painting. However, the software was never released as the developers thought it simply emulated the processes of previously well-defined studio exercises and therefore it lacked originality and a suitable educational approach for online learning.

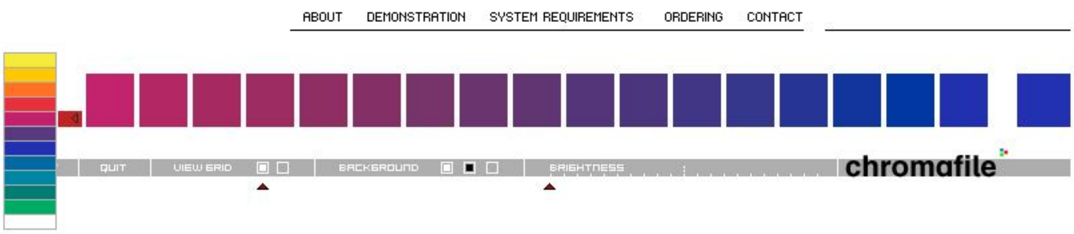

Figure 4.4: Demonstration of how Chromafile simulates paint colour mixing on screen.

Two researchers at the Bergen National Academy of the Arts in Norway developed an application called *Chromascope* (Smedal & Jacobsen, 2005). The software is based on perception and allows users to create colour combinations by using sliders. Similarly, at Purdue University, Bendito (2005) developed a computer-aided technique: ART 302 Color Design[24]. It is based on Itten's teaching philosophy, to allow experimentation with the fundamental principles of colour design; the application uses a series of custom colour palettes and 2D digital drawing functions (Figure 4.5 provides an example of a colour exercise). For both these systems no reports of systematic educational evaluation have been found.

An e-book to teach colourimetry to computer science students was developed by Schanda et al. (2002) at the University of Veszprem in Hungary. This CD based *Colour e-book* offers a series of simulation experiments and animations as well as descriptions of the colour phenomena. This discipline mostly deals with digital and printed colour, hence paint-based workshops were not suitable. On the other hand, the demonstration and visualisation possibilities were limited in the lecture theatre while the darkroom visual demonstration

23 http://www.chromafile.com/
24 http://web.ics.purdue.edu/~pbendito/color_design/index.html

experiments were not practical for the number of students they had to accommodate hence the e-book provided a clear advantage when used in conjunction with the lectures.

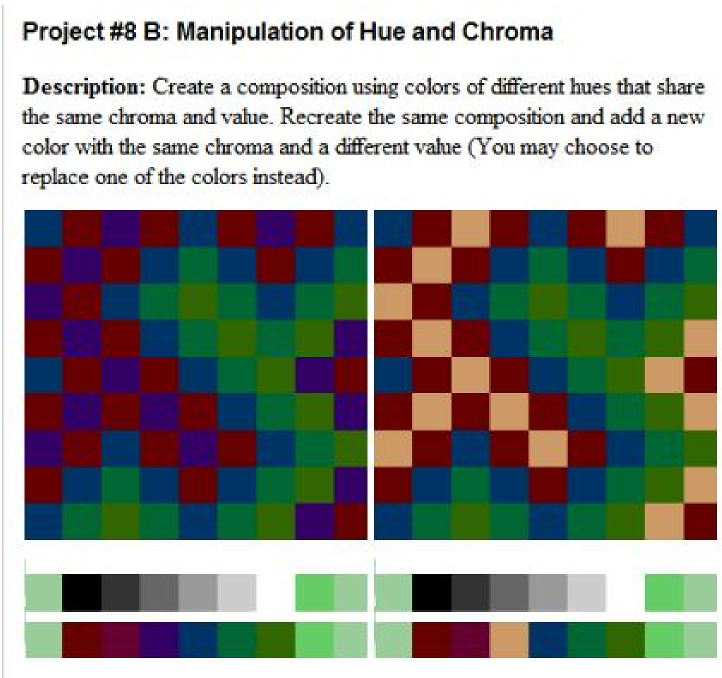

Figure 4.5: A print screen from ART302 Color Design virtual learning environment. The image shows an example of a Hue and Chroma exercise.

A research project that used an Immersive Virtual Reality environment to teach colour theory was the *IVR Museum of Colour* (Spalter et al. 2000). The project was developed as part of the *Exploratories*[25] project at Brown University, USA, for teaching aspects of colour theory through a series of science museum-like experiments**.** The researchers faced challenges with regards to the interface and interaction in the VR environment (Figure 4.6). They followed an architectural structure in which each floor housed experiments of increasing conceptual difficulty. Simple interactive experiences with different parameters of a colour such as value, hue and saturation were placed on the first floor, experiments dealing with groups of colour were on the second, and interactive comparisons of colour spaces were on the third. Although the environment could be experienced on a desktop computer the researchers found that the immersive experience was qualitatively different. Nevertheless, this project was experimental in nature and did not continue to an immersive form and consequently was never evaluated (Spalter, 2004).

The *Society of Dyers and Colourists* created the *Colour Experience*[26]: an education resource for children and adults hosted on the web and at their headquarters in Bradford, UK. The website hosts a series of online galleries and interactive sections on all aspects of colour. The

[25] http://www.cs.brown.edu/exploratories/freeSoftware/catalogs/color_theory.html
[26] http://www.colour-experience.org/

Virtual Colour Museum houses interactive exhibits that teach about colour, light and dyes. The website and the museum offer general knowledge with regards to colour and its applications, covering areas ranging from fashion to history, nature and dyes. This is meant to be an educational resource for the general public but it could be used in higher education colour courses as an introduction to colour or as a pointer for further reading.

Figure 4.6: A user interacts with the IVR of Museum of Colour developed at Brown University, USA.

Publications and reviews regarding colour theory courses are limited. This section presented examples of the different approaches to colour courses for which published material could be obtained. There are a number of websites offering explanations of colour theory concepts accompanied by 2D images but the majority have not been designed with a learning and teaching methodology in mind. Furthermore, even the courses reviewed in this section apart from mentioning student engagement and motivation do not provide a formal evaluation of the educational effects of the course. Spalter et al. (2000) have evaluated the usability of the digital learning environment from a technological viewpoint such as interface and interactivity issues, display size and so on. Kwon & Kim's study (2002) was the only one reporting an educational evaluation of their web-based colour course. They qualitatively analysed the students' work, peer reviews and questionnaires and the results showed that the system had positive impact on the learners' learning and motivation. The same system was further developed and evaluated again in 2004 (Kim & Chung, 2005).

In summary, this review has been brief because only a small number of researchers has undertaken work and published in this field. However, what becomes evident from the review is that the majority of computer-based applications have not exploited the possibilities of modern technology to create new, innovative and engaging learning applications for colour theory. The typical exercises seem to have been mechanically converted into a 2D digital form and now are offered on-screen rather than on paper.

2.3 Why is Colour Education Important?

Why is colour education important? Judging from the current state of colour courses offered by higher education, one might think that educating artists and designers on colour theory and application might not be essential at that stage as they will probably gain the required knowledge through their professional career. Undoubtedly, students gain some understanding and training on colour through projects and they are expected to acquire a more in-depth, subject-specific knowledge once they engage with their chosen major at a professional level. However, apart from providing some general knowledge, the existence of colour courses could offer the additional benefits explained below:

Skills

A colour course could provide students with confidence and skills, and fuse experimentation and creativity in the use of colour (Spalter et al. 2000). The more one knows and understands colour, the more one will be able to confidently and skilfully use it as a tool to express ideas. Taste and talent are obviously advantageous qualities, but for professionals a great amount of knowledge and understanding is also required (Smedal & Jacobsen, 2005). Bergstrom (2002, p. 965) claims that it is important '*to train one's sensitivity for colours so that one can play with them like a skilled musician on his instrument, but you also need the musical notes, a colour language with which to communicate and document colours*'. Novice artists and designers have more or less developed intuitions towards colour yet these subjective responses could be further enriched and cultivated through a well-designed course (Akbay, 2006).

Communication

Colour education can enable students to effectively communicate colour information (Epps, 2006). For instance, in the textiles and interior design fields, communication and specification of colour between designers, manufacturers, suppliers and consumers have always been challenging; linguistic, cultural, and technological differences impede the effective communication of colour information and colour specification. Therefore artists and designers need to be aware of this colour language in order to accurately identify and communicate the colour they wish to use (Bergstrom, 2003). The dissemination of universal colour coding systems has not been properly implemented in basic colour courses and definitely needs more attention.

Dissemination of colour research findings

Colour education plays an important role in disseminating colour research results to students. Janssens & Mikellides (1998) reported that 60% of the students who took part in their study had not read any books, magazines, or articles on colour and only a few students had read several. One third of the respondents could recall a TV program on colour, while only one in ten had attended a course on colour outside their school. These findings indicate that the overwhelming part of knowledge about colour research comes from basic colour education. However, apart from informing the students about recent work and findings deriving from the fields of psychology, physics, anthropology, computer science, etc. a colour course could also help to make these fields known to students; knowing more about colour may inspire students to pursue a career in one of these fields and thus promote colour research (Bergstrom, 2003).

Lastly, colour education is important because students think it is important. Most studies have shown that students are eager to learn more about colour and in particular about colour perception, emotions and preferences, cultural influences and current trends. When Mottram (2006) interviewed two contemporary artists (Catherine Yass and Liam Gillick), in order to enquire about the use of colour in their works, she found out that they had not been provided with a course in colour at their universities. This of course had had no deleterious impact on their careers but they both indicated that their formal education had not addressed the topic of colour in any depth and that they would have been interested to attend such courses. Mottram (2006, p. 416) explains that '*even if actual practice may not require an in-depth understanding of colour vision, colour measurement or colour naming, the fundamental nature of their contribution to seeing and the seen suggests that these topics should be understood by students of the visual arts.'*

3. Identify the Educational Problem

The difficulty in learning and teaching colour is innate to the complex nature of the topic. Attempting to define 'colour' may lead to more confusion:

> *'…the colours we see do not exist on the surface of substance, for they are manufactured in the mind's eye. Our experience of colour is a subjective sensation conveyed through the energy in wavelength form of light radiations within the visible spectrum, however, without an observer, light rays do not, in themselves, constitute colour'.* (Porter, 1979, p. 39)
>
> *'the difficulties inherent in attempting to quantify sensations have meant that "colour" – the subjective outcome of an objective process of stimulation – has rarely been considered in a comprehensive way'* (Gage, 1999, p. 11).

Colour is a sensation that humans experience from a very young age and thus have prior knowledge of. Therefore, people's opinions on colour are already formed before they enter higher education which makes its teaching challenging (Miele, 2002). Many of the students who have already studied colour elsewhere and possibly gained some basic knowledge become confused when they discover that their previous beliefs and concepts could be in contradiction to what is being taught in the colour course. Arnkil (2005) suggests that the ideas and approaches instilled at this formative stage tend to direct the students' attitude toward colour for the rest of their lives.

From an educational perspective, the colour courses, when provided, can be problematic as mentioned previously for often they do not offer a balance between theory and practice. Most colour lecturers, especially in Art and Design schools, are inclined to give priority to practical colour exercises and applications to the disadvantage of more theoretical lectures and presentations (Janssens & Mikellides, 1998). Marsden (2002, p.298) noticed that there is a degree of 'unwillingness' on the part of some studio-based tutors to become involved in the delivery of the theory. Marsden's view is that these educators may lack experience and understanding of, and / or confidence with, the subject.

Albers and Itten's course duration was long enough to allow for the theories to emerge through practice while now that the courses are much shorter the learners are still expected to grasp the concepts without the necessary learning conditions. When practical assignments are not linked to any theory, they can lead to limited learning that does not transfer or generalise well. Students tend to concentrate more on how to mix paints accurately and to cut out colour samples from magazines rather than reflecting on the purpose of the exercise.

On the other hand, didactic lectures on colour theory with no visual teaching aids or practical activities, can lead to shallow learning, as students do not connect the theoretical concepts to real-life situations. Black and white handouts can be ineffective for building connections between symbols and visual recollection of colours, effects or illusions. In such cases, learners find it difficult to master the concepts and hard to get motivated, as I also witnessed from my experience.

Students who are willing to gain a deeper understanding of the subject might resort to textbooks on colour, however *'they are apt to find themselves in a wasteland where initial studio experiments and forays into books are no assurance of understanding and clarity'* (Willard, 1998). Further challenges arise for learners as the boundaries between art, physics, psychology, psychophysics, chemistry and philosophy blur when investigating colour. Arnkil (2005, p. 82) has noticed that almost every book on colour written for artists begins with a chapter on *The Physics of Light* and *The Anatomy of the Eye*; *'A diagram of Newton's prism experiment and a cross-section of the eye seem to be compulsory iconography, repeated almost religiously in book after book'*. He believes a combination of contemporary scientific findings, artistic vision and pedagogical clarity is lacking from those colour books (Arnkil, 1995).

With regards to digital instruction, some Art and Design tutors argue that it happens too fast without allowing time for reflection or questioning (Smedal & Jacobsen, 2005). Choosing, picking and applying a colour with the mouse or stylus pen on a computer screen cannot be compared to using paints to create colour samples. After the learner experiences the task once or twice the process becomes automatic and somehow subconscious. Hence, digital learning environments must be based on innovative teaching methods and tasks that lead to deep understanding of the subject by being engaging and enjoyable, and above all by fostering reflection and critical thinking.

The majority of the concepts of colour theory have to do with knowledge construction and not fact learning. Knowledge construction benefits from integrating new knowledge to previous beliefs and from a deep analysis of new content, whereas fact learning can be achieved through the request and provision of information. Methods for teaching colour theory that fall into the category of request and provision of information obviously fail to create a suitable learning condition for the concepts to be learned.

So what seems to be the educational problem with current colour theory courses where they exist? Educational theory suggests that a better balance between theory and practice should result in a learning experience that is both more effective and more enjoyable. The educational theory of constructivism supports the concept that people do not just receive or reproduce, but actively (re)construct, new knowledge and understanding founded on what they already know and believe (Larochelle et al. 1998). This is also expressed in Laurillard's model (1993) of the teaching and learning process, which asserts that all well-designed teaching will attend equally to both the public, abstract, conceptual aspects and to the private, concrete and experiential aspects of a topic, as well as creating connections between them.

In fact, it is desirable to connect new ideas being taught to three things: firstly, to the prior concepts (whether right or wrong) the learner may have embraced; secondly, to their prior experiences of colour and of using colour, especially since people experience colour from a very early age – it is not sensible to try to teach even a simplified theory that cannot deal with facts that the learner already knows; thirdly, to their present experiences – although some learning occurs without any actions being performed, it is also clear that important learning occurs by attempting tasks. Therefore, it is necessary to align learners' tacit knowledge (prior concepts) of the subject matter to the new theoretical knowledge being offered by applying the theory into practice. Educators need to build on these personal conceptions and experiences in ways that assist learners to achieve a deeper understanding of the subject. Inglis et al. (1999) argue that education can go wrong when theory is separated from practice and / or when barriers between them prevent this interplay. According to Cobb (1999) as cited in Marsden (2002, p. 292) *'the equality and depth of the learning experience is usually found to be enhanced when technique and theory are taught within the framework of a project'*. Since colour is a perceptual experience, this is both particularly important and relatively easy to arrange.

Laurillard (1993) also emphasises the importance of a dialogue between the teacher and the learner where the teacher can analyse the student's conceptions on a certain subject and determine the future nature of the dialogue depending on these ideas. However, the increase of student numbers within the studio environment has rendered face-to-face communication among tutors and students a scarce resource. Since most Art and Design subjects are based on knowledge construction and not fact learning, dialogue and externalisation of ideas and problems is used for generating ideas and constructive arguments, and encouraging students to further express themselves verbally, visually and / or textually. Thus, an activity designed to instigate exploratory learning could propel students to reconsider their beliefs and encourage them to use their existing knowledge to grasp the new concepts under investigation. In general, the design of learning materials should be preceded by an investigation into what the target learners typically think, rightly or wrongly, about the topic. It should also include practical activities where possible, partly because people learn by exercising the ideas they are trying to learn, but even more to link the theory to practical experience. In short, what could improve learning and teaching of colour theory is a method that relates theory and practice: involving personal experience and action (in the spirit of studio-based teaching) with some basic theoretical concepts, without requiring large amounts of time from teaching staff.

4. The Proposed Solution

In view of the analysis of the educational problem, and the recent and ongoing changes in Art and Design institutions that have resulted in limited time and space for face-to-face tutorials and intensive workshops, this study proposed the use of a computer-based tutoring method for learning basic concepts of colour theory. Apart from the obvious benefits that a media- or online-based learning application can offer – such as allowing students to learn in their own time, pace and place, and making use of the infinite colour combinations possible on screen – it could also make abstract concepts more concrete when an appropriate pedagogical method is supported by explanatory 3D visuals.

Several studies have shown that 3D VEs are particularly appropriate for teaching complex and abstract concepts and since colour space has an inherently three-dimensional nature, this could offer a significant advantage (Winn, 1997; Salzman et al. 1996; Dalgarno, 2002). The third-dimension is considered important in order to communicate these concepts yet so far it has been ignored in the majority of exercises carried out in the studio or via the computer as demonstrated from the review presented above. Therefore, the assets proposed for this digital learning method are the design and implementation of an innovative tutoring method and the use of 3D visuals.

The aim of this research was not simply to propose the use of 3D computer graphics, but to design, implement and assess a novel teaching strategy that could offer satisfying learning outcomes and increase learners' motivation and enjoyment. Several educational theories were identified suitable for digital delivery of the subject and an attempt to incorporate them in the proposed learning activity has been made. In addition, the following key pedagogical points had to be taken into account when designing the teaching strategy:

a. The ethos of current learning and teaching methods in the discipline of Art and Design
b. The importance of balance and establishing connections between theory and practical experience
c. The educational value of a constructive dialogue between learner and tutor
d. The role of visuals, and in particular three-dimensional visuals, for this particular topic

It is anticipated that if the above key points are properly embedded in the learning application, then learners would be able to enjoy it, reach a high level of engagement and thus achieve a deeper understanding of the concepts presented. In order to evaluate the effectiveness of this proposed 'Learning by Exploration' (LBE) method a human tutoring method was initially developed. The design of this learning activity is presented in the next section.

5. Designing the Learning Activity

The following strategy was pursued in order to design and evaluate the LBE method to improve learning and teaching of the basic concepts of colour theory:

1. First, an existing educational problem was identified: the difficulty in learning and teaching colour theory concepts especially those which are inherently three-dimensional (section 2).

2. Then the existing problem was analysed using educational theory (section 3).

3. A solution that could resolve the current educational issue was proposed: a 3D computer-based LBE method (section 4).

4. In order to evaluate the educational effectiveness of the proposed method a human tutoring technique was initially developed. A human tutoring approach allows rapid changes and improvements to be noted as well as detailed observation of the learning and learners. Having a human simulate what will eventually be done by a computer, the so-called 'Wizard of Oz' technique (Kelley, 2005; Preece et al. 1994, p.541) is an established rapid prototyping technique in Human Computer Interaction.

5. Then experimental testing of alternative solutions was carried out e.g. learning from existing textbooks versus the human LBE method.

6. The evaluation and refinement of the tutoring method should inform the development of the technological solution. The human teaching is converted into an interactive learning application.

The learners' tests were conducted in collaboration with Morven McWhirr, a final year psychology student at the University of Glasgow, following our common supervisor's suggestion that our research interests could be combined in the same experiment. Her dissertation investigated whether people can acquire knowledge by interacting with exhibits when visiting museums and in particular science museums. Since 'colour' was considered a topic that can interest all people and not only Art and Design students, she was keen to carry out her experiment on this subject. The design of the learning activity and the structure of the experiment was a collaborative effort, while I designed the aspects that related to colour and she focussed on the quantitative analysis of the data.

The rest of this section presents the educational objectives of the suggested tutoring method, the educational theories embedded in the design of the activity, the subjects who participated in the evaluation, the selected educational topic, the educational media used and compared, and the structure of the experiment.

5.1 Educational Objectives

The learning activity focused on demonstrating to learners the concept of hue, saturation and value (HSV) 3D colour space as part of an introduction to colour ordering systems. In addition, the terms of tint, shade, primary colours and complementary colours, etc. would be touched upon through the LBE activity. Basically the main educational objective of this study was to teach learners the three dimensions of colour (HSV). A more analytical account of the chosen topic is provided in section 5.4.

5.2 Educational Theories

The design of the tutoring method was largely inspired by the educational theory of constructivism, which was discussed earlier in this chapter and in Chapter 2. This section explains in more detail the educational value of 'dialogue', which is often neglected in the design of digital learning applications. Communication among learners and tutors and among peers is an integral part of studio teaching in Art and Design. The intention here was to create some sort of written and/or verbal feedback mechanism that could challenge the learners' existing ideas and encourage them to search for the right answers. Since it is difficult to achieve an automated intuitive dialogue between the system and the learner, the idea to use a pre-defined set of prompts emerged. These prompts could be offered to the learner contingent on to his / her progress. This idea was first tested with a human giving the prompts to the learners (following the 'Wizard of Oz' technique).

The teaching method should be responsive to the learner. In theory, after the student performs an initial task in the application, the system should recognise his / her conceptions or misconceptions about the topic, and then logically select a suitable course of action in order to either progress to the next task (if the first was carried out successfully) or generate a series of prompts that could help the user reconsider his / her ideas and progressively lead him / her to achieve a deeper understanding of the topic.

Marton & Ramsden (1988) identified the importance of highlighting the inconsistencies within and the consequences of the learners' conceptions, since in this way they become more explicit to them. One means of achieving this has been by presenting a 'devil's advocate' line of questioning (Walker, 2004). In order for teaching discourse to be successful in argument generation, it must contain challenges, counter arguments and clarification. Challenging and probing questions are particularly effective in facilitating the students to construct an argument that they could then develop, defend and support (Walker, 2004). Therefore, for the development of the LBE method it was desirable to incorporate a dialogue that would not provide answers, but would encourage learners to generate their own answers; this could be achieved through the use of challenging questions, counter arguments and clarification. This method allows for knowledge to become public and for both parties to become aware of the learner's ideas.

Socratic Questioning (SQ) was identified as one means by which this could be accomplished. Carey & Mullan (2004) found that the definitions of SQ differed in the literature, and they quoted the following authors:

> *'The Socratic method of interviewing encourages the client to contemplate, evaluate, and synthesize diverse sources of information, most of which were already available to the client'* (Overholser, 1987, p. 258).
>
> *'Inductive dialectic procedure leading a person to accept or admit the desired conclusion by means of a progressive series of leading questions that are answered in turn.'* (Corsini, 2002, p. 921)

Padesky's (1993, p. 4) idea of SQ involves asking the participants questions which: (1) they have the knowledge to answer, (2) draw their attention to information which is relevant to the issue being discussed but which may be outside their current focus, (3) generally move from the concrete to the more abstract so that (4) they can, in the end, apply the new information to either re-evaluate a previous conclusion or construct a new idea. These definitions may have been retrieved from publications related to psychotherapy and philosophy but the Socratic method of inquiry has also been used in education as a recognised tutoring approach (Schön, 1987, p. 84; Edelson, 1996; Trella et al. 2000). A SQ method was therefore incorporated in the design of the learning activity with the intention to resolve some of the identified problems of the current teaching methods.

In addition to the SQ method, consideration has also been given to the *contingent tutoring* proposed by Wood & Bruner (1974). The 'contingent shift principle' is a technique in which feedback is provided to a learner depending on his/her level of success with a task. This implies that the amount of tutoring any individual receives is the minimum possible, thus allowing them to maximise learning for themselves. Similarly, in this study, the participants received differing numbers of Socratic style prompts dependent of the number of inconsistencies in carrying out the series of tasks. Pratt & Savoy-Levine (1998) utilised this method for teaching maths to pupils. The researchers found that the contingent tutoring condition was more effective than other tutoring methods in terms of how long the information was retained. Schmalhofer et al. (1990) found that learning a programming language by exploration with a selective tutor was most effective as opposed to learning with a constant tutor or no tutor. These earlier studies have also suggested that pupils enjoy the contingent learning principles more than other tutoring methods hence it was also interesting to test out whether or not this preference for contingent tutoring also exists in adults.

With these points in mind, a learning activity based on contingent-Socratic tutoring method was designed to demonstrate basic colour theory concepts. The participants were given the opportunity to explore the relations between colours by arranging coloured tiles, as it will be described further on in this chapter; contingent and Socratic prompting should encourage deeper understanding of the relations, and result in self-construction of the concepts of HSV. In turn, the deeper understanding of colour theory produced by utilising these techniques should maximally suit the learning of concepts rather than learning of facts.

5.3 Participants

In total, 56 participants took part in the study: 48 people participated in the comparative study and 8 in the evaluation of the pilot digital version.

From the 48, two participants' data were excluded as one was colour blind and the other was unable to complete the follow-up test. Thus a sample of 46 participants remained. Of these, 28 were female and 18 were male. The mean age of participants was 28 years, and the groups were approximately matched for age and gender. The majority of participants were students currently engaged in an undergraduate or postgraduate degree. Ten of those participants had an Art and Design background. No difference was found between males and females, and so all data reported is pooled between genders.

All eight postgraduate students (five males and three females) who took part in the evaluation of the digital version had current experience of using the 3D modelling software, so that familiarity with the user interface conventions would not be an issue. They had knowledge of how to perform basic actions such as moving 3D objects, grouping multiple objects together, changing camera views, applying colours, etc. Their backgrounds had a connection to Art and Design and they all had experience of creating digital work using 2D and 3D graphics software and hence using colour palettes.

My role in this study was to meet with the participants individually and conduct the learning activity or give them the text passage depending on which group they have been assigned to. Morven McWhirr, the second researcher, carried out the same process with almost 60% of the participants while I conducted all the digital-version tests. In 15 occasions both of us were present. This gave the opportunity for one of us to observe the procedure, and take notes and photos during the trial.

5.4 The Topic: Runge's Colour Sphere

The topic of HSV colour-space, and in particular Philipp Otto Runge's (1777-1810) colour sphere, was selected for this learning activity for several reasons. Using the colour sphere, one can teach most of the basic concepts of colour theory such as hue, saturation, value, shades, tints, primary, secondary, tertiary and complementary colours. In addition, the sphere was a conveniently limited and suitable concept for this initial experiment as the intention was to try out the overall LBE method. Furthermore, as mentioned previously, all modern colour systems are three-dimensional and hence are difficult to represent and understand via books, diagrams and 2D graphics, so this study provided the opportunity to test whether a material and a digital 3D model of the colour sphere could be effective for demonstrating and comprehending these concepts.

Itten presents the 12-hue colour circle in his book, which depicts the primary, secondary and tertiary colours as seen in Figure 4.7 (Itten, 2002). However, he acknowledged that the circle was inadequate for a complete classification therefore in order to provide a clear and complete map of the *world of colour* he used the sphere –the solid that Runge adopted in 1810 when he published *Die Farbenkugel* (the Colour Sphere), the same year Goethe published his *Zur Farbenlehre* (Theory of Colours) (Gage, 1999). While Goethe presented the colour circle (Figure 4.8b), Runge went schematically a step further by describing a three-dimensional sphere for organising all conceivable colours according to HSV. Figure 4.8a depicts Runge's original drawings of the sphere.

The 12 pure hues are positioned around the globe's equator, while the two poles are occupied by white at the top and black at the bottom creating a greyscale along the central axis. Across the surface of the sphere, the colours are graded from black to the pure hue to white, in seven steps (Figure 4.9). Intermediate mixtures theoretically lie inside the sphere. This spherical colour mapping serves to visualise the rule of complementaries, it illustrates all fundamental relationships among colours and between chromatic colours and black and white.

Figure 4.7: Itten's 12-hue Colour circle.

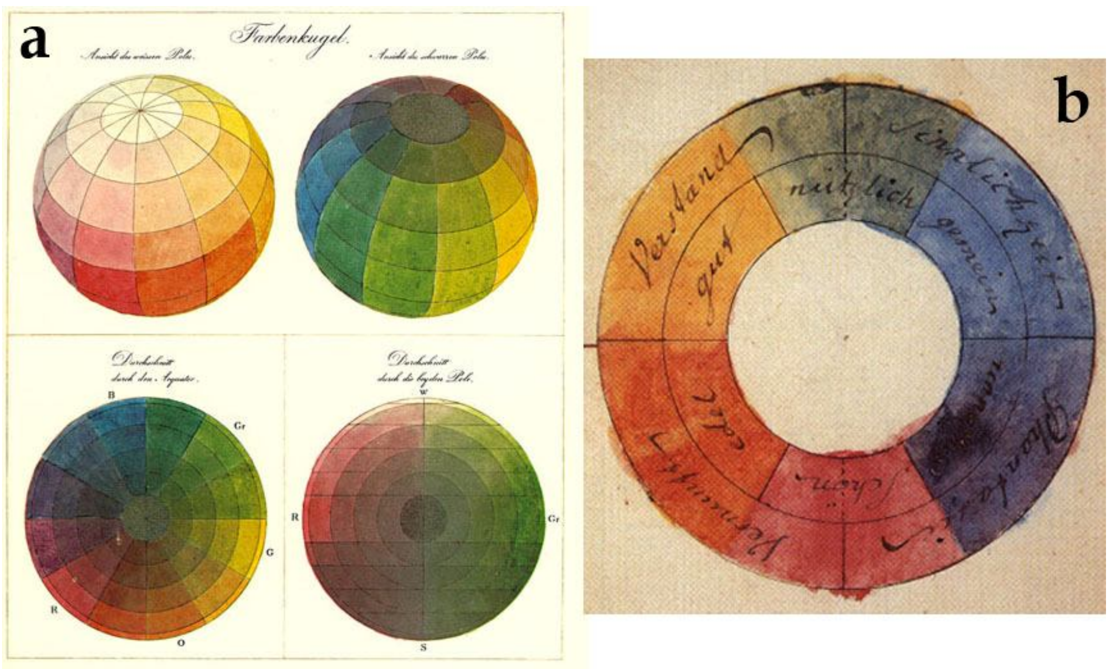

Figure 4.8: (a) Runge's Colour Sphere
(b) Goethe's Colour circle. Both drawings were published in 1810.

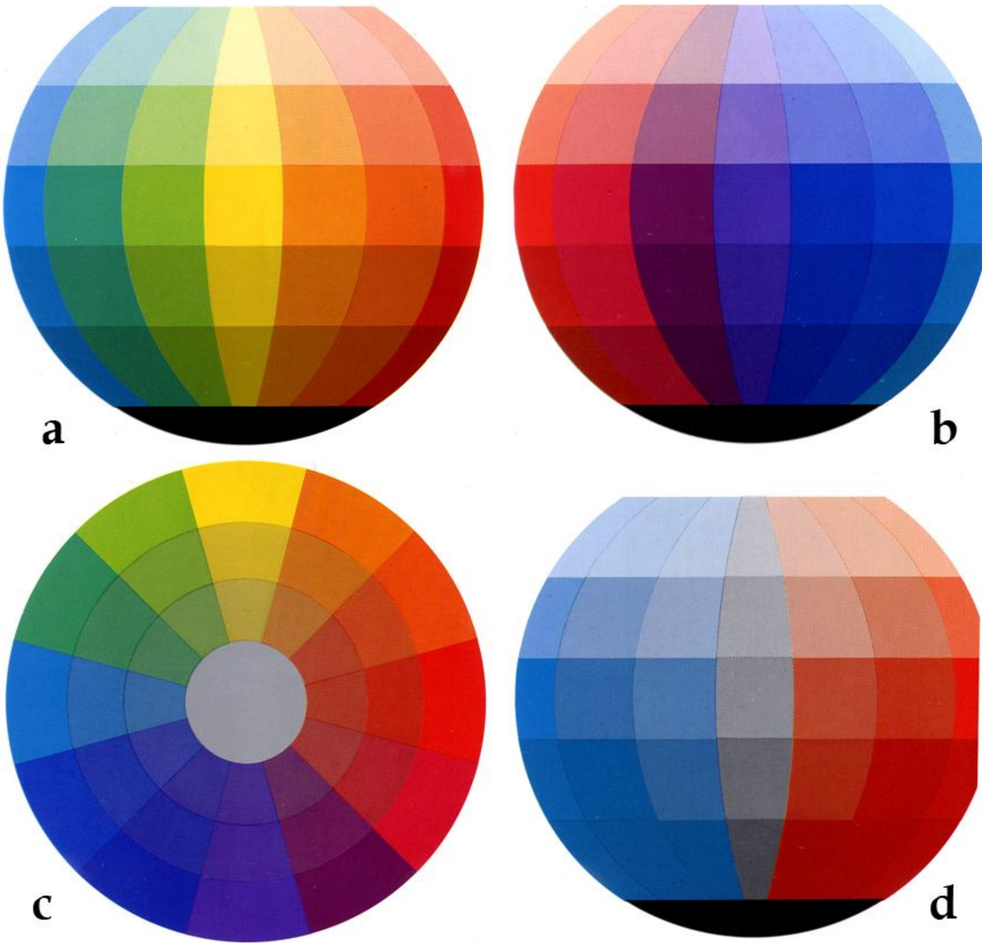

Figure 4.9: (a) and (b) show an equatorial view of the view of the colour sphere.
(c) shows a horizontal section of the colour sphere at the equator
(d) shows a vertical section of the colour sphere, taken in the red-orange / blue-green sector.

Runge selected the perfect symmetry of the sphere, instead of using a double cone for example, because he believed that only through this shape could ‘a completely neutral grey’ occur at the centre by mixing diametrically opposed colours from the surface towards the core (Silvestrini & Fischer, 1999). Furthermore, the sphere is the elementary shape of universal symmetry and it was also used to symbolise the ‘world for colour’. Runge’s sphere it is also the ancestor of the most modern systems of surface-colour, and it has often been cited in the literature of colour-measurement, although its ideal symmetry has not proven adequate for modern conceptions of colour-spacing (Gage, 1999).

Other similar colour mapping systems for pigment mixing that follow a more phenomenological approach are Albert Munsell’s (1858-1918) colour-tree, Wilhelm Ostwald (1853-1932) double pyramid and the NCS’s (Natural Colour System) double cone among others. Silvestrini & Fischer (1999) provide an extensive account of the various systems on a website dedicated to colour[27]. The website also provides a virtual 3D model of Runge’s sphere

[27] www.colorsystem.com

that the viewer can pan and zoom in. Some of the colour spaces involve complex shapes and technical details such as colour coding and coordinates. For this first experiential activity it seemed more suitable to use a less complicated model to serve as an introductory medium to the basic theories of colour.

5.5 The Educational Media

Three different media were used in this study:

1. a cardboard model of the colour sphere, referred to here as the *material version*;
2. a 3D digital model of the sphere, referred to as the *digital version*; and
3. a text excerpt describing Runge's colour mapping concept.

The study basically used the material version in order to evaluate the educational effectiveness of the LBE method and it contrasted its results to the ones that derived from the text version. Since the study envisaged the development of a digital learning application as part of the proposed solution, the same LBE method was tested using the digital version with eight participants in order to explore the advantages and disadvantages as opposed to the material version.

5.5.1 The material version

The material version consisted of four sets of coloured square tiles sized 5.5x5.5cm; each had a different uniform colour. The base of the tiles was created from white thick cardboard material while the colours were printed on normal A4 paper using a laser printer and then glued on the cardboard surface. The four sets were:

1. a black-white sequence (Figure 4.10a);
2. a red-white sequence (Figure 4.10b);
3. a red-black sequence (Figure 4.10b); and
4. 12 fully-saturated hues selected to represent the primary (red, blue, yellow), the secondary (orange, green and violet) and the tertiary colours (yellow-green, blue-green, blue-violet, red-violet, red-orange and yellow-orange) (Figure 4.10c). However, some in-between colours were also printed and presented only to the learners who failed to notice the relation between two or more of the 12 hues.

The sequences consisted of a pure colour at either extreme, between which there were eight cards, the colour of which was created by mixing the two extremes in varying proportions.

Figure 4.10: The images show the tile sequences: (a) black to white (b) a short sequence from white to red to black (c) 12 fully-saturated hues.

The Scandinavian Colour Institute (NCS Colour Centre) has been developing similar material, like those tiles, for use on different levels of colour courses and studies for more than 50 years. Even advanced students appreciate this starting approach of arranging coloured tiles and working with collages. *'To touch and treat the colours this way is a pure training for the eyes and at the same time it is a simple and easy way to establish an understanding of a structure that really feels "natural".'*(Smedal & Jacobsen, 2005, p. 75)

The model for the spherical skeleton was created from thick white cardboard. It consisted of a tube forming the centre of the vertical axis, which was coloured with a grey scale gradient going from white at the top to black at the bottom. Six circumferential rings indicated the surface of the sphere. The equator of the sphere consisted of a solid cardboard circle. This was solid in order to provide better support to the structure. Furthermore, 12 Velcro tabs were equally spaced around the circumference of that circle, while one of the rings had eight Velcro tabs attached to it equally spaced from the top to the bottom. A Velcro strip was placed at the back of each tile so as to allow for easy attachment and removal of the cards to the model. A photo of the sphere skeleton can be seen in Figure 4.11.

5.5.2 Text version

A written explanation of the Runge's colour sphere was presented to the participants who had been randomly selected to be provided the text version instead of the interactive version. The description included an image of Runge's original drawings of the concept. The text version was created from combining information from three textbooks. The three excerpts were joined in order to provide a more coherent description of the sphere than what could be offered solely by one source. The A4 page as given to the subjects can be found in Appendix A. This was selected as the text version, to allow a real comparison to be drawn between learning and teaching of the colour sphere as provided through textbooks, handouts and text-based online material to the interactive version. The image was presented in black and white, as it had been depicted in the textbooks it was extracted from.

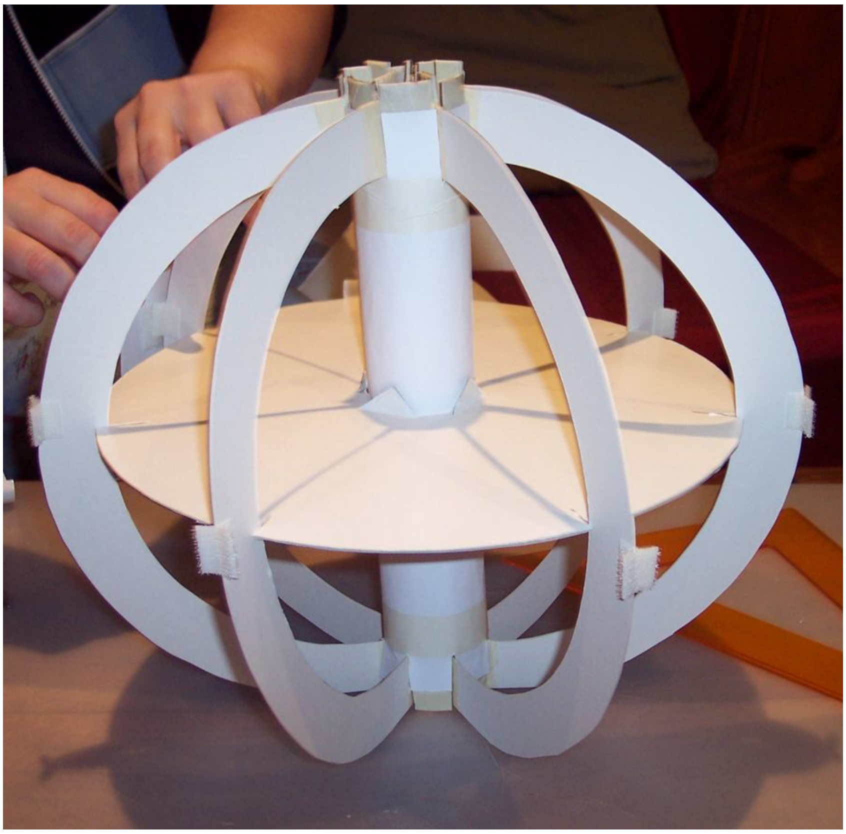

Figure 4.11: The cardboard sphere

5.5.3 The digital version

The objects that comprised the material version were digitally created using a 3D modelling software package (Maya) to replicate the learning activity using a digital medium. Note that the digital version described here is not a final learning application product. The 3D software was utilised as a digital learning environment as it allowed the user to interact with 3D models on screen using a mouse and the keyboard. The same testing process was followed: a human tutor presenting the tasks and asking probe questions while, on this occasion, the learner was arranging digital models rather than cardboard ones. Hence, the digital version was not a preliminary version of the end product. The development of a stand-alone interactive learning application was not deemed suitable at the early stages of this study as the initial aim was to determine whether the LBE method could be effective for teaching colour theory. Only after the method had been evaluated and the results analysed would it be reasonable to begin the creation of the application. Nevertheless, the rationale for testing the same tutoring method with both physical and digital objects was to identify the differences between them in terms of interaction and in order to determine what adjustments would have to be made in the tutoring method if it was to be provided via a computer-based application.

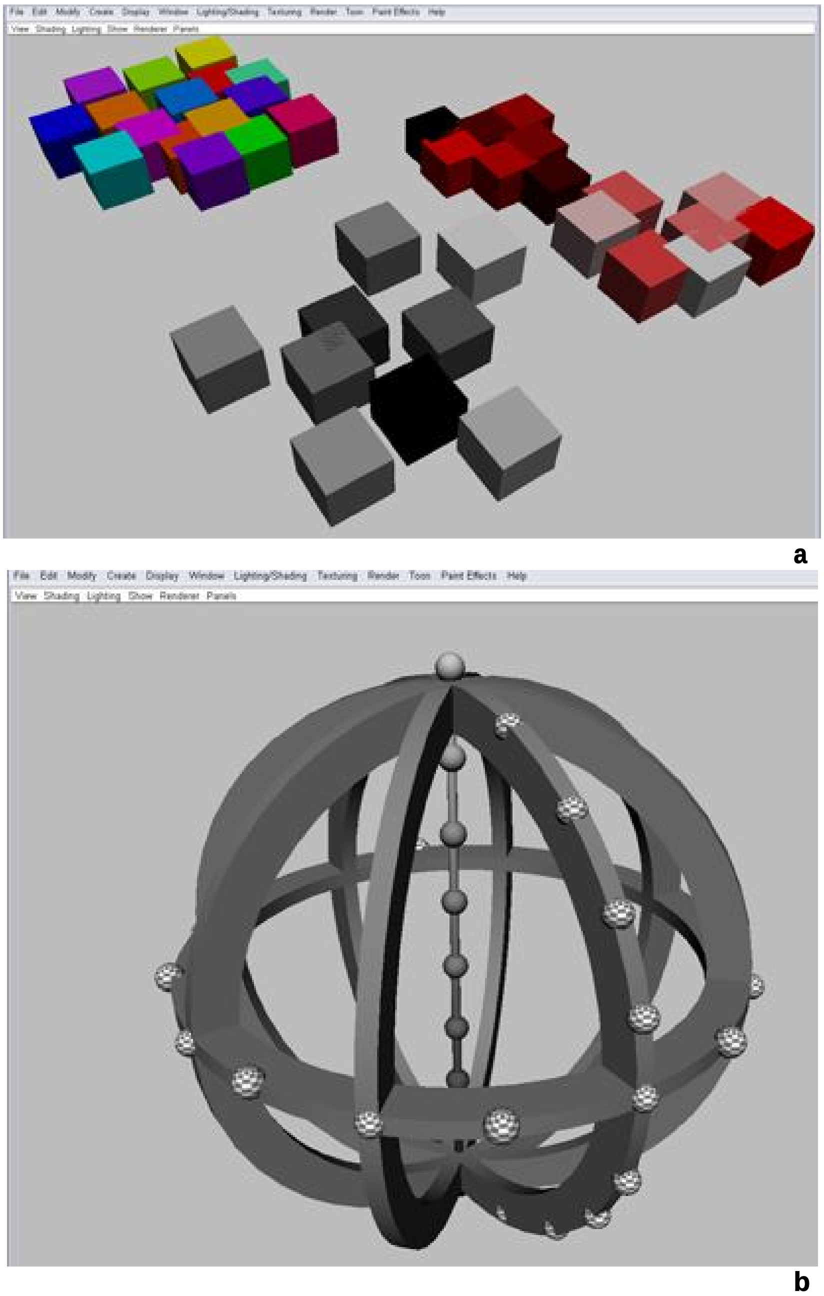

Figure 4.12: (a) The digital colour cubes and (b) the 3D sphere, as viewed through the 3D modelling software.

Nonetheless, adjustments and alterations had to be made in order to create the digital objects since interaction with tiles on a table-top and on screen differs in many ways. For instance, the tiles were represented as cubes in the 3D environment so as to be viewed from all angles (e.g. top, side, front and perspective) (Figure 4.12a). The tiles were flat mainly because it was harder to construct cubes with cheap and durable materials. The 3D software provided the opportunity to do this effortlessly. The same colours as presented above were applied on the cubes and the four sets were placed in four different groups.

The sphere skeleton followed a similar structure in the digital version (Figure 4.12b). Nevertheless the way the cubes were attached on the sphere had to be altered as it was deemed too difficult for learners to place them accurately on the surface of the 3D model through the software. This task is not impossible but it could take someone who is not very experienced in 3D modelling a long time to complete. The task has to be fairly easy so as not to distract the learner from the main objective of the activity. So, instead of having users placing the cubes on the skeleton, small grey spheres had been integrated on the model where the Velcro tabs had been attached on the material version. Then a colour palette containing all the colours used in the experiment was created within the software to allow users to choose a colour by clicking on it and then dragging it on the small spheres to apply it (Figure 4.13). This way of attaching the colours on the 3D model proved to be easier and faster. In addition the interface of the software had been customised to make it look less complex (e.g. the menus and tools that were not needed had been hidden during the experiment). The adjustments discussed here may not be required if the digital learning application gets developed. For example, the 3D sphere could offer a snap function so the cubes could be easily placed on the corresponding points; this is not an action that the 3D software could offer.

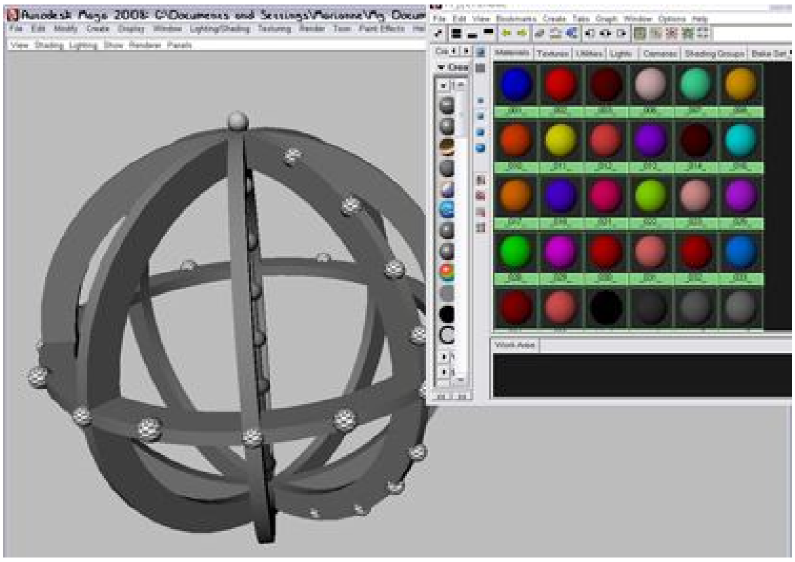

Figure 4.13: The colour palette and the points on which user applied the colours in the digital version

5.6 The Design of the Study

This study aimed to assess whether the developed LBE tutoring style could preferentially achieve greater understanding of the selected colour theory topic as opposed to a textbook condition. The hypothesis was that the LBE condition would induce greater learning than a text condition and furthermore this difference would be most pronounced over a delay period. In addition, the LBE condition was expected to be more enjoyable in relation to the text condition. The evaluation was conducted using both quantitative (e.g. number of right answers) and qualitative measures (e.g. observations). The LBE-digital version was evaluated separately with a smaller number of participants (eight); the observations conducted during this trial are presented in section 7.2.

The comparative study utilised a 2 (intervention – material and text conditions) x 2 (time of testing - immediate and delayed tests) between subjects design. The two conditions were the LBE-material version and the text condition. The time of testing was either an immediate test or a delayed test. The purpose of the delayed tests was to measure retention and understanding of the concepts presented. The mean length of delay was ten days with a minimum and maximum delay of six to 17 days. The 46 participants were randomly assigned to one of the four groups:

1. Group 1: LBE and immediate test;
2. Group 2: text and immediate test;
3. Group 3: LBE and delayed test; and
4. Group 4: text and delayed test.

The eight participants who were assigned to the LBE-digital version had prior experience of using the software; this method was too experimental and thus not suitable to present to people with no training in 3D modelling. The procedure of the LBE method was the same for Group 1, Group 3 and the digital group (Group 5). The participants of Group 5 were all assessed with an immediate test. Their data was not compared to these of the other groups.

6. The Study

All the participants were asked to sign a consent form before starting the trial. The trial sessions were conducted with one learner at a time by one of the two researchers. Apart from the sessions that involved the digital version, the trials using the other conditions did not take place in one particular location as the materials were portable and the skeleton could be assembled in less than five minutes. For half of the sessions both researchers were present in the room but only one interacted with the learner while the other observed the session. The three different conditions are presented here in turn.

6.1. Learning by Exploration: LBE-material version

The learners who were assigned to perform the LBE trial were told that the study was investigating ‘the best way to organise colours’. They were initially presented with all the tiles in front of them and were asked to arrange them in the way they felt best organised them. This was done to test whether the participant was already familiar with the concept of HSV colour space. Following this, the tiles were collected by the researcher and returned to the participant according to a set procedure. For each set of tiles the participant was asked to '*arrange the colours in the way that he/she felt best organised them*'. The order of presenting the sets was as follows:

1. white to black
2. red to black
3. red to white
4. white to black and red to black
5. white to black, red to black and red to white
6. the fully saturated hues
7. the fully saturated hues, and white to red
8. the fully saturated hues, white to red and red to black
9. the fully saturated hues, white to red, red to black and black to white

During the presentation of the sequences, the learner was initially given only eight of the ten cards with two cards removed: the third one from either extreme. After the eight colours had been arranged the participant was provided with the missing two from the set and asked to integrate them into their organisation. This showed whether the subjects applied systematic organisation to their arrangement.

At the end of each arrangement the participant was asked to provide a rationale for his/her formation. The purpose of this was to prompt the learners with greater awareness and understanding of their arrangement since providing explanations to others results in self-clarification of the concept that they are explaining. Moreover, it provided them with the opportunity to recognise and reconcile inconsistencies. Before proceeding to another set, the participant was asked whether the colours were arranged in the way he/she thought was best. This question was raised in order to reiterate to the learner the aim of the task and to allow the experimenter to refer back to the arrangement at a later stage. The participants only moved to the next stage if they thought that their arrangement appeared satisfactory to them or if they were not completely satisfied with the formation but could think of no better way to arrange the tiles. In a situation like that the participants were asked to explain what they thought was problematic with their arrangement.

In addition to explaining their final arrangement of the cards, the subjects were given a number of prompts, contingent on their actions. The prompts were:

1. *Why does colour X go in position Y and not position Z?*

   This was used in a variety of situations.

2. *Before with these same cards you organised them like A and now you have them organised like B, why is that?*

   Utilised to bring inconsistencies in subjects' reasoning to their attention.

3. *Why have you done it like that?*

   Delivered at the end of each sequence. In addition, if subjects then changed their organisation of the cards prompt (3) was asked again.

4. *Why is colour X at the end of the line? Does it make any difference which colour is at the end of the line?*

   Delivered after the presentation of the colours in a line (often the rainbow), to evoke the idea that colours may be organised in a circle.

5. *Can you think of any other way to arrange them which might solve that?*

   Used in a variety of situations, commonly after the subject had explained what they perceived to be a problem with their arrangement.

6. *If I gave you these additional colours, how would you arrange them now?*

   Extra colours were provided to bridge the perceived gap between colours, i.e. in situations where a participant could not see a relationship between two colours.

7. *If I take these colours away, do you now concede that all the colours are related in some manner, if there were a sufficient number of intermediary colours?*

   The extra colours provided in (6) are removed. This reiterates the result of (6), and explains that it was not possible for all conceivable colours to be provided with these tiles.

8. *Other/Not a pre-defined prompt*

   Used on miscellaneous occasions, dependent on the individual. In no situation was a participant explicitly told a concept, or asked to alter their arrangement. This prompt took the form of questioning based on an irregular response made by a participant.

All prompts were given in order to make the learner think deeply about the arrangement they had provided as best. In no situation were subjects asked to rearrange the cards in any particular manner, the prompts served to provoke the subjects to question their arrangement for themselves and to reorganise it if they felt it was necessary.

Therefore, after all the sets of tiles had been organised according to the learners' judgment, they were collected back by the researcher. The members of Group 1 were then given the sphere model and the analogous number of tiles as the Velcro tabs. The members of Group 3 were handed the sphere at their second session usually scheduled a week after the first. The participants were asked to think about the ways that they had arranged the tiles on the tabletop and place them on the model in a way that made sense to them or in the way that might solve some of the difficulties they had experienced when arranging the tiles. It was pointed out to the participants that black was at the bottom and white was at the top, and that the black to white continuum was represented by the grey gradient tube in the middle hence the black to white sequence was not provided. In addition, every second card from the white to red and red to black sequence had also been removed. Once they were handed the model no prompts were given to either group.

Upon successful completion of the model another set of questions was addressed to the learner. The model was considered successfully completed when all the tiles were attached in the right positions (Figure 4.14). However, if a participant had two tiles in the wrong position, but had clearly grasped the concept of the model, this was also regarded as successful completion.

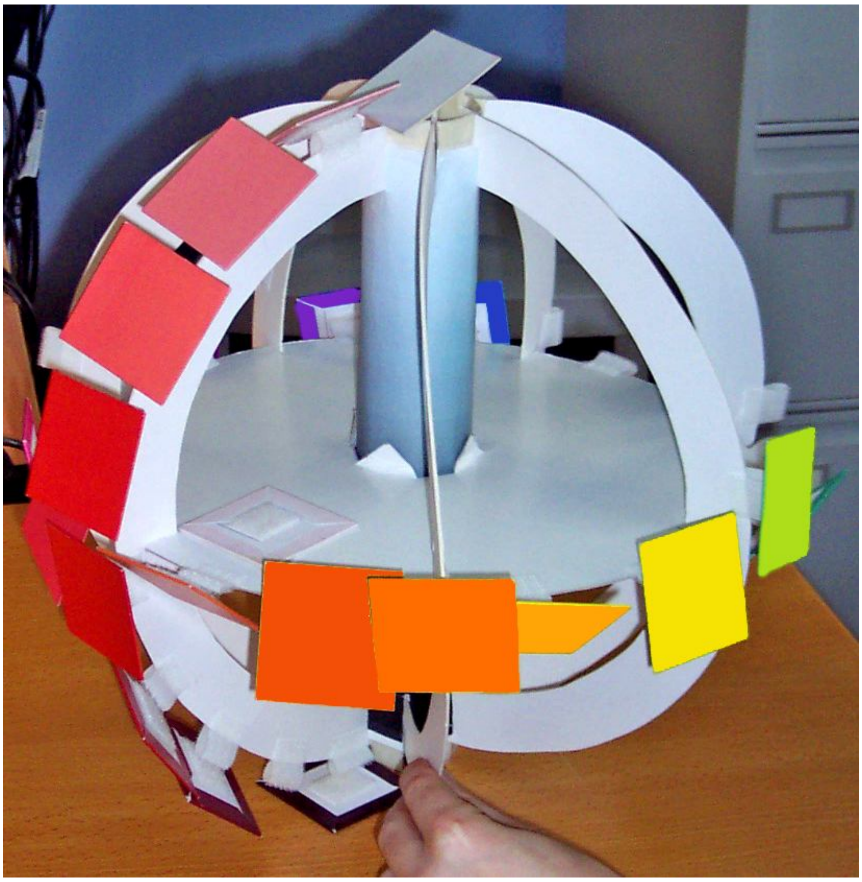

Figure 4.14: the photo shows a successfully completed colour sphere.

The test questions were:

1. *What colour goes here?*(the researcher pointing half way between green and black) [1 point]

2. *What colour goes here?* (the researcher pointing half way between red and grey) [1 point]

3. *Describe what the colour at this point would appear like?*
   Subjects were required to describe a colour so that the researcher could select it from a colour swatch. This ensured that there was a shared understanding between both parties of the appearance of that colour. [1 point]

4. *Where would brown fit in this model?*[1 point]
5. *What is good about this model?*
   The participant had to provide an answer which intimated an appreciation that the model showed the relationship between all the colours available in this experiment. Moreover, that the model in theory contained all perceivable colours. [2 points]
6. *If you had the same basic concept, so that white is at the top and black is at the bottom, with the pure hues around the centre, could they be organised using another shape (e.g. a cylinder, double cone)?*
   Subjects needed to demonstrate an appreciation that the concept of the HSV relationships could be organised using other shapes and that this was only an example of a spherical arrangement. [1 point]

Model completion was scored as one point while the top score for answering all questions correctly was seven points, adding up to a total knowledge score of eight (1-8 scale). At the end of each session the participants were asked to rate their enjoyment of the tasks on a scale of -5 to +5.

6.2 Text Version

The participants of Groups 2 and 4 were told that the study was looking at colour theory. They were informed that they would be presented with a passage detailing a concept for arranging colours. They were asked to read the passage in their own pace and informed that the length of time they needed to read the passage would be recorded, but it was stressed that this was in no way important, and they should take as much time as necessary. They were then presented with the passage. The model of the sphere along with the correct number of tiles was presented to the participants of Group 2 immediately after reading the passage, whereas Group 4 was handed the model another time, usually a week later. The learners were asked to think about the text they had read and arrange the tiles on the model in the way it has been described in the text. The same testing process as the one described above was carried out with these two groups as well.

6.3 Learning by Exploration: LBE-digital version

The same process as the one used for the LBE-material version was also followed with the participants of Group 5. Nevertheless, some adaptation had to be made as the interaction with the 3D objects differed. For instance, the four sets of cubes had been placed in four layers which were all hidden at the beginning of the task. Then the visibility of each layer was turned on to reveal a sequence. The completed sequences, rather than being moved to the side as they would have on the table, were made invisible so as to not clutter the 3D working area. When they were required for further use, the layer was turned on again. In the beginning of each session the researcher urged the participant to use any views he/she wished (e.g. top, front, side or perspective). These learners had the opportunity to work on three dimensions whereas the rest sorted the tiles using mainly two dimensions.

Furthermore, when the 3D sphere was shown to the participants, they were asked to arrange the colours on it, not by attaching the cubes to the corresponding points but by painting the points with the appropriate colour. Hence, they had to select a colour from a custom palette and then click and drag it on top of the point to paint it. Only the colours of the cubes were provided on the palette to avoid confusion. For test question 3, a colour sample on screen was utilised instead of a paper one. In brief, apart from the differences mentioned here the rest of the process remained the same, as the same prompts and test questions were offered to this group too. Figure 4.15 shows a completed digital colour sphere.

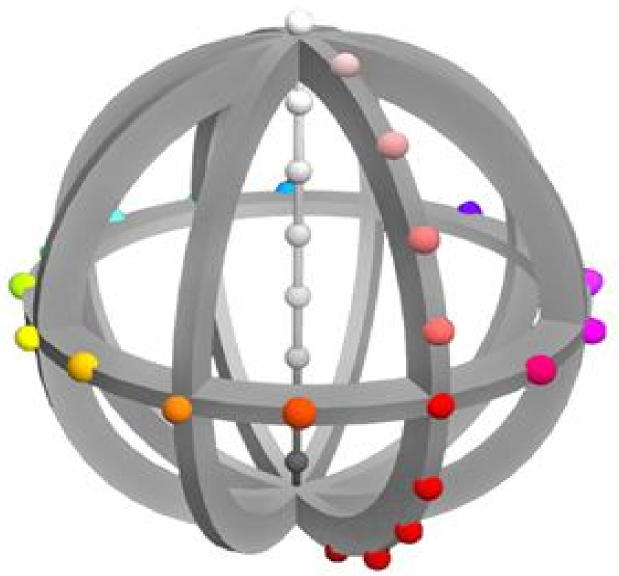

Figure 4.15: the image shows a completed digital colour sphere

7. The Results

The quantitative data collected from the learner trials are presented below. The observations made while the participants were performing the tasks are also offered in this section. The quantitative data that derived from the LBE-digital version are not provided here as this version was created in order to get a glimpse of how participants may interact with digital objects rather than tactile physical ones, hence only the observations are discussed.

7.1 The Quantitative Data

This section presents the quantitative data as derived from the comparative study between the LBE-material version condition and the text condition, for both immediate and delayed tests. To reiterate, the groups were:

1. Group 1: LBE and immediate test;
2. Group 2: text and immediate test;
3. Group 3: LBE and delayed test; and
4. Group 4: text and delayed test.

It was hypothesised that model completion and understanding would be greater in the LBE condition than the text condition, and that this would be most pronounced over a delay period. It was found that 67% of Group 1 could complete the model compared to 42% of Group 2. In the delayed tests, 92% of Group 3 completed the model successfully, while only 25% did from Group 4. The percentages are depicted in the graph in Figure 4.16.

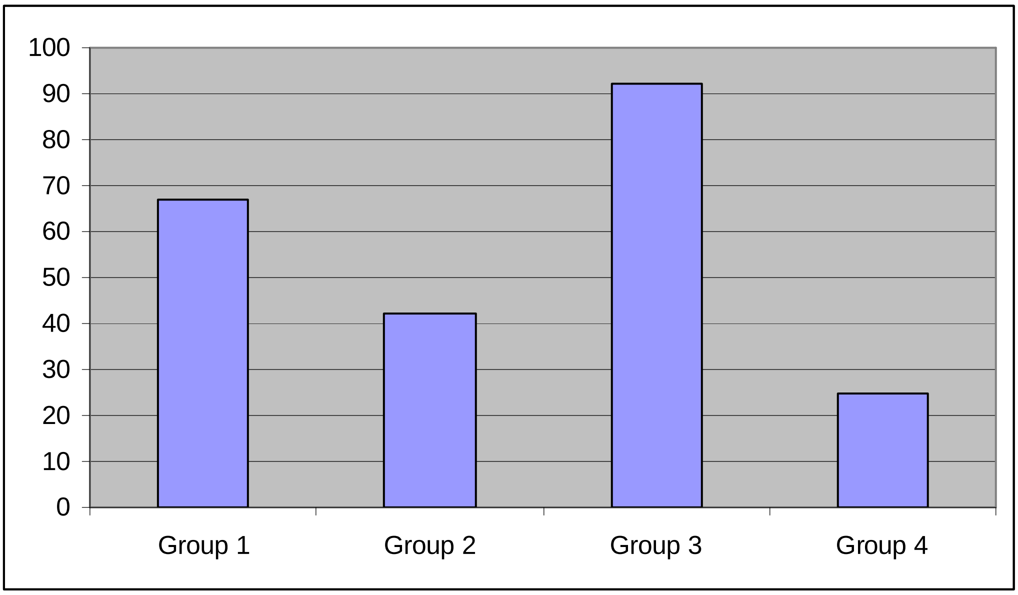

Figure 4.16: The chart shows the percentages of each group of the participants who completed the model successfully.

The differences between these conditions were tested formally using an ANOVA[28]. A significant difference was found to exist between the Groups 3 and 4 ($t = 3.831$, $p = 0.0023$). Thus, the LBE condition might not have an immediate advantage compared to the text condition, but for the delay Groups 3 and 4, the difference was significantly greater. Therefore the hypothesis was partially confirmed.

Model-understanding was measured according to the number of correct answers to the test questions. The highest possible score for model-understanding was 8. The mean

[28] The ANalysis Of VAriance (or ANOVA) is a powerful and common statistical procedure in the social sciences. In short, is a concept/calculation to analyze variation and determine its significance.

understanding of the model for the immediate test Group 1 and Group 2 was 4.4 and 1.3 respectively, while for Group 3 it was 5.6 and 1.4 for Group 4. The chart in Figure 4.17 shows mean model-understanding score for each group.

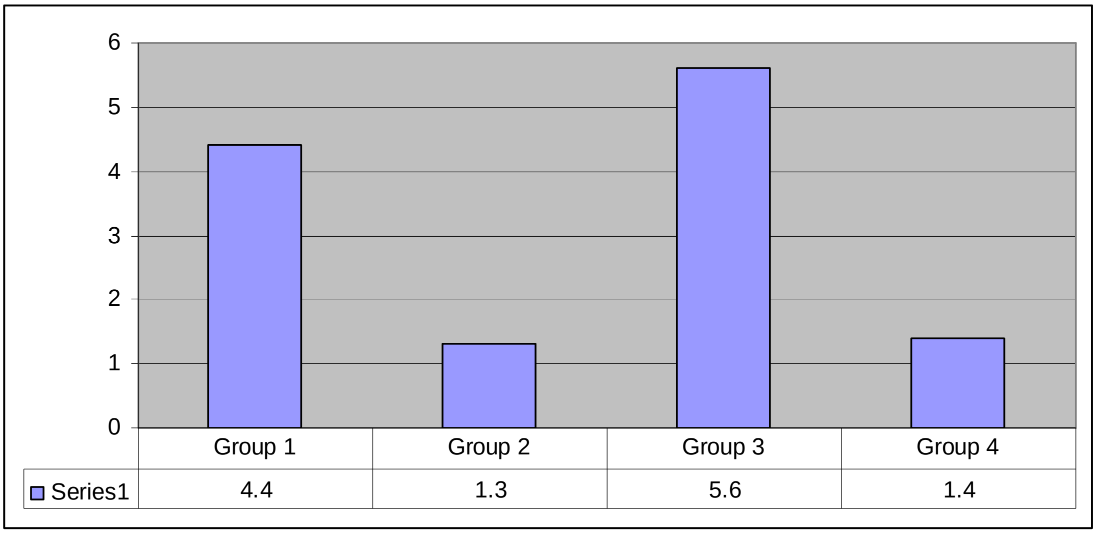

Figure 4.17: The chart shows the mean for model-understanding for every group.

It becomes apparent from the graph that there is a similar pattern to the previous data, yet this graph shows more pronounced differences. A significant difference was found between Groups 1 and 2 ($t = 2.788$, $p = 0.0382$). This entails a significant difference in model-understanding between LBE and text conditions with an immediate test. It was also found that model-understanding was significantly different between the Groups 3 and 4 ($t = 4.145$, $p = 0.0009$). Moreover, the difference in model-understanding was greater after a delay period, with a mean difference between the groups of 4.2 after a delayed test and of only 3.1 with an immediate test. This shows that model-understanding can be better achieved with the LBE condition and that the advantages are greater after a delay period.

The data was further analysed to investigate the relationship between conditions and model-understanding only among those who were able to complete the model. The graph in Figure 4.18 shows that the participants of Group 4 who completed the model had a better model-understanding than those who completed the model immediately after reading the text (Group 2). It was found, using Tukey simultaneous tests, that model-understanding was significantly different between Group 1 and Group 2 ($t = 4.061$, $p = 0.027$). However there was no difference in model-understanding in the delayed condition between LBE and text ($t = 0.459$, $p = 0.9674$).

Moreover, the time spent arranging the tiles as well as the time spent reading the text was contrasted to model completion and model-understanding results. However no significant difference was found between the duration of interaction with the tiles and model completion. Similarly, there was no significant difference between reading time and model completion. Time and model-understanding correlation showed no significant differences either. In addition, there was no significant difference between those able and those unable to complete the model with the number of prompts received.

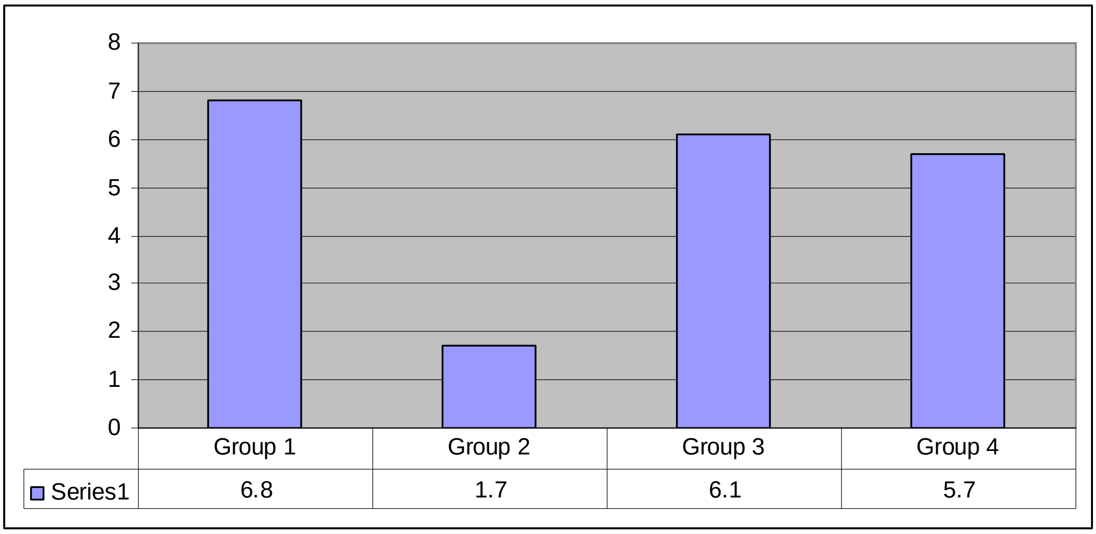

Figure 4.18: The chart shows the average model-understanding only among those who completed the model successfully.

Furthermore, the participants rated their level of enjoyment of the learning activity and the test experience using a scale from -5 to +5; the average enjoyment score for each group is provided in Figure 4.19. The mean enjoyment score for both groups that participated in the LBE activity was 3 while for all those who were given the text was 0.6, thus demonstrating a significant difference in enjoyment between the two learning methods.

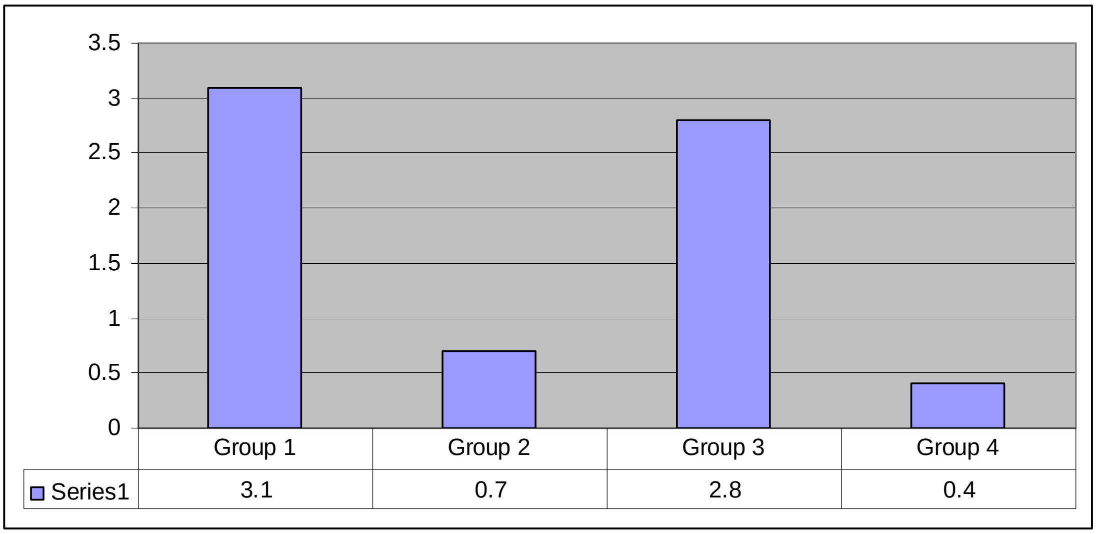

Figure 4.19: The chart demonstrates the average enjoyment score for each group.

7.2 Observations

While the participants were performing the tasks, notes, photographs and some video were taken by the second researcher, who was not interacting with the learner, in order to record the process.

The first strong impression was that those who performed the LBE-material version of the learning tasks found it enjoyable, and indeed absorbing. Even those who took over an hour to complete them all were surprised at how the time had passed and none showed any signs of fatigue or boredom. These participants often used the word ‘play’, while the ones who performed the LBE-digital version considered it more like a problem-solving task. None of this could be said of those given the text version.

Every person arranged the coloured tiles in a different way. In terms of spatial relations, the patterns the participants formed varied from straight lines, circles and triangles to squares, spirals, stars and zigzag diagonal patterns (Figure 4.20 and Appendix A). From the viewpoint of the educational concept being explored, the tacit view was that for the black-white, red-black and red-white sets a straight line was best, while for the hues a circle was better. The best way to combine all the sets would require three dimensions. The fact that the cardboard tiles were square in shape (instead of being triangular or circular for example) often seemed to influence people to use square or rectangular layouts. They also tended to reason in terms of the number of tiles in the current problem e.g. if there were nine, then a three by three square layout might be attractive. Increasing the number of tiles and using probe questions that required them to add an extra tile or two to a completed layout tended to reduce this type of reasoning (which is demanded by some tests of spatial intelligence).

With regard to the colour properties the learners were expressing in their spatial layouts, some organised them according to hue and brightness, while others grouped them as cool and warm. Many said they arranged them in terms of their brightness even in cases where the samples they were working on had been intended to show equal brightness; given that the colours were not printed on a professional printer this entailed that perfect samples could not have been produced. Only a couple of the learners argued that colours should be randomly scattered and one stated that colours are organised like music notes.

Watching participants' moving the tiles as they assembled a layout often made it clear how important placing colour samples side by side is for comparing small nuances in colour. This can be done extremely rapidly and conveniently with cardboard tiles on a large tabletop: it seemed to be an important feature to support in any computer implementation.

One of the reasons for developing the digital version was to provide the participants with the option to utilise the third dimension, which a flat tabletop might prevent them from considering. They were told at the beginning of the test that they were free to use all the views available in the software (orthographic and perspective) and switch between them. Yet most digital participants performed the task by using for the most part the top view (using X and Z axes) and did not consider using the third dimension (Y axis). Even when they were prompted to view their arrangement from a different perspective, most of them switched back again to two dimensions. One explanation for this is that a 2D arrangement requires less effort. Another reason might be that often tasks as such presented via a computer are usually 2D hence learners are used to the 'flat' traditional layout.

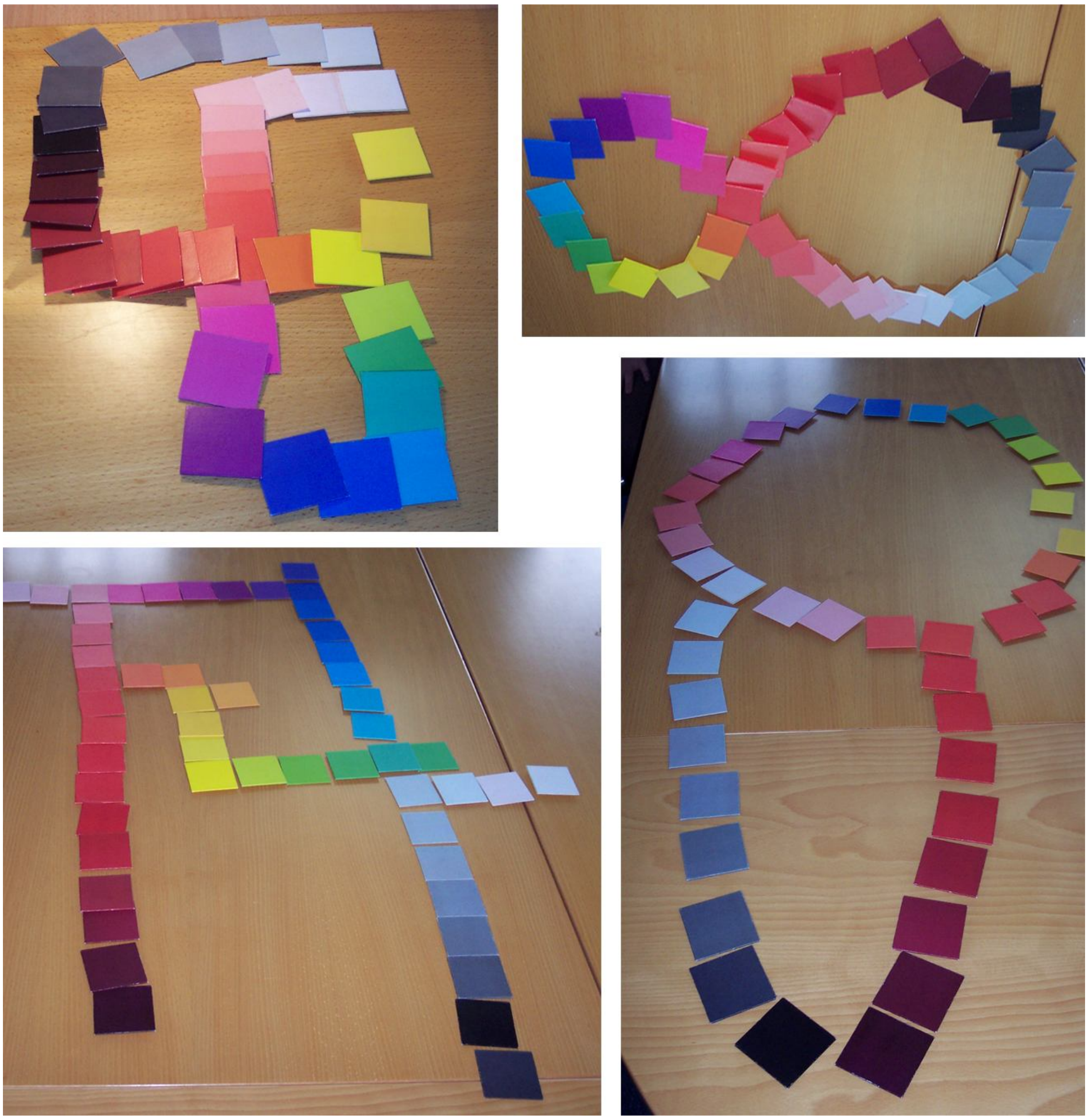

Figure 4.20: Various arrangements of the coloured tiles

In the early development of the tutoring method, it emerged that the number of tiles in a set was a significant issue. From the point of view of rapidly sorting samples on a given dimension, a small number seemed most convenient. However for getting learners to see a set as a smooth sequence of a single varying property, a powerful intervention or question was to offer another intermediate value and ask where it could be inserted into an arrangement. Introducing more and more fine distinctions seems important in dislodging people from the opposite tendency of seeing colour in terms of a small handful of landmark primary colours with no particular relationship to one another. This is in fact a form of a very general educational tactic that can be important in quite different areas, sometimes known as 'bridging' (Brown & Clement, 1991; Brown & Clement, 1989; Brown, 1992). Basically it is about suggesting to the learner to consider an intermediate case midway between two cases they regard as poles apart and unrelated, in order to see a connection between them.

The great variety of ways of arranging the tiles, both spatially and in terms of the colour properties expressed, was true for all the participants regardless of their backgrounds. Initially it was anticipated that the educational and vocational background of the subjects would play a significant role on their performance. A total of 18 participants had an Art and Design background (ten took part in the comparative study and eight in the LBE-digital version). One might assume, since artists and designers apply colour extensively in their works in the form of pigments or digital colour, that they would have had a mental model of colour relations in their minds. Surprisingly enough, their performance did not differ from that of the other participants. On the other hand people related to computer science seemed to be more familiar with the HSV relationships, probably because they know why the colours in graphics software are represented with a similar 2D or 3D arrangement, whereas other users of such programmes might not be questioning the way colour selection is offered to them. It shows, however, that this kind of approach is effective at eliciting from each learner the properties of colour they are already aware of and which ideally they need to relate to any abstract theory or organising principle. This remains true even for concepts such as 3D colour spaces, that they only express some properties of colour.

It was noticed that the majority of the participants did not have a clear mental model of how all possible colours could be related before the 3D sphere model was presented to them; however after arranging the tiles in each task, most of them provided good reasons to support their schemes. When the 3D sphere model was presented to them, most of them agreed that it related colours in a coherent way and so they tried to revise their conceptions. A literal interpretation of the notion of constructivism and of SQ is that each learner should construct the target concept for themselves, perhaps under the impact of experiences and questions arranged by a tutor. In essence, this was the aim of the LBE method, but in most cases was not fully met in this preliminary version. However, the impression from the observations was that this may not matter; model-completion and model-understanding was achieved with many of the LBE participants even if they did not come up with the 3D colour arrangement by themselves.

8. Discussion

8.1 About the Findings

The comparative study showed that LBE was a more effective method for learning and teaching the chosen colour theory concept than reading a text description of it. It was also found that understanding of the topic was greater after a delay period for the LBE participants. In the immediate test conditions, the difference in completing the model was not significant between the LBE and the text, but model-understanding was found to be greater with LBE. An explanation for this is that participants who completed the text condition had learned enough in order to be able to construct the model, in a similar manner to those who had the LBE, but this initial learning was not deep enough to also lead to model-understanding. Hence, these learners simply applied the information that was offered through the text without reaching a deeper understanding of the whole concept. When faced with the test questions, they were unable to understand or intuitively work out the 3D colour space concept. This was in contrast to the LBE condition, where learners had first interacted with the tiles and had faced the challenge of creating a satisfactory arrangement. Thus when the sphere was presented to them they were able to make the connections and sort out their inconsistencies. Deep and shallow learning provide one explanation for this finding. That is, shallow learning enables participants to construct the model: to regurgitate the information provided immediately before the test. However, answering probing questions successfully requires deeper understanding of the whole concept.

The participants of Group 4, who were given the text and tested after a delay period, also performed poorly in terms of completing and understanding the model. Shallow learning seems to deteriorate with time as learners did not retain the information. It appears though, that only those who understood the whole concept in the text condition were able to retain the information throughout the delay period and complete and understand the model (referring to Figure 4.18). Chi et al. (1994), in a study testing the educational value of self-explanations, found that the pupils who had received a similar prompting tutoring style answered more questions correctly than a control group who had just read a passage on the topic twice. Furthermore, they found that those participants who had received prompting were more able to answer increasingly difficult questions as opposed to the text group; this was due to the deeper level of understanding attained by the prompted group.

Another finding of this study was that the number and type of prompts given to the participants had no impact on the model-completion results. This could be due to the contingent tutoring method that was followed with the LBE participants: they were provided with a prompt when it was necessary and not on a set basis. As such, this contingent method could be an efficient means of teaching as learners are supported when necessary, which eventually reduces wastage of the tutor's time. Nevertheless, it was noticed that prompt 5 (*'can you think of any way to arrange them which might solve that?'*) was only given to those who were unable to complete the model. It seems that this prompt was used with the participants who expressed that their arrangement was not perfect but did not feel compelled to attempt to resolve it without prompting. Generally, there was not one important prompt that was necessary for completing and understanding the concept.

A key issue with the findings of this study is that although the LBE condition generated significantly greater comprehension of the chosen colour concept, it is important to acknowledge the pay off between depths of understanding and length of time taken to reach that understanding. Several studies have reported that methods that slow the rate of learning can have a positive effect on retention and transfer. Earlier digital learning applications on colour theory had not incorporated a 'delay' in their design leading tutors to complain that digital instruction happens too fast and does not allow learners time to reflect on their decisions. Common sense would suggest that this LBE takes too much time and would be impossible to carry out with a large number of students, that is why this study envisaged the digitisation of this learning activity: to reduce the tutor's teaching time for subjects of colour theory that are not usually offered in practical workshops. The feasibility of converting the human tutor into an intelligent tutoring system will be discussed below.

Another interesting issue that arose from the results and observations was the role of the testing stage in the learning activity. In essence, the participants in the LBE condition were guided with prompts until the sphere was presented to them; after that point they were given no further feedback. It is often the case that following a tutoring phase, learners may believe they have grasped the concept, and it is not until they are tested on it that they realise that they may not have understood it as clearly as they had thought. At this point learners go through a period of teaching themselves during the test. Hence the role of a testing phase in the learning activity could be twofold: first it could inform the learners (and tutors) on whether the concept was understood or not and second, it could challenge learners to work out a way to resolve the problems with their arrangement. The testing phase could be seen as a problem-solving activity on its own, but the earlier stage is required in order to achieve deeper understanding of the concepts.

As mentioned previously, an experimental LBE-digital version was created to test the tutoring method with 3D digital objects too. The quantitative data and observations did not suggest any difference in the educational effectiveness or enjoyableness between the LBE-material and LBE-digital versions. However each method had advantages and disadvantages; these are discussed in the section 8.3.

Finally, a finding, which was to some extent anticipated, was that participants found the LBE method more enjoyable than the text condition. This is important since learning is more likely to take place when the task is enjoyable and, in effect, the information provided could be more memorable. It could also encourage learners to find out more about the subject, meaning that the method managed to stimulate their interest and capture their attention.

8.2 Limitations

The evaluation of the LBE tutoring method demonstrated that some issues need to be resolved before proceeding to the development of the digital learning application. These issues mostly concern the educational objectives that this study attempted to address. Some educational objectives have been met, while others require a refinement of the learning activity in order to be better communicated and understood by the learners. Here I discuss the issues that arose from the trials.

To reiterate, the colour theories that this learning activity aimed to teach were: the concept of HSV colour space and the definitions of hue, saturation, value, shade, tint, primary, secondary, tertiary and complementary colours. These comprise a set of basic colour theory concepts. So, even if these theories are to be presented to the students in a practical workshop or a lecture, this activity could be conducted in parallel, at a preferable time and place, to make the knowledge gained more explicit by demonstrating the relationships between the colour properties in a 3D virtual environment. Hence, initially the intention was to create this activity to support the other colour teaching methods by offering a balance of theory and practice.

However, informal questions to the participants showed that they had not connected the technical terms of *hue, saturation and value* to the corresponding tile sets or the three dimensions. This was not surprising since these are not mentioned in the version of the LBE method tested so far, while they are of course mentioned in textbook treatments. This first attempt of the LBE approach focussed more on the practical / interaction part and neglected to offer the theory and terminology. Undoubtedly, the activity has to include these elements to provide learners with some theory so that they can ground it in their experiential knowledge. This is also necessary if a full balance between practice and theory is to be achieved. Still, this should be an easy improvement to make. A way to provide the technical definitions of the concepts needs to be devised in a subtle manner so as not to interrupt the flow of the activity, whether during or at the end of the practical phase (e.g. presenting the tile sets according to the colour property, i.e. *'can you arrange these tints?*' or *'can you arrange the shades of the red hue?'* or by using the words in the prompts).

Furthermore, the activity did not involve any tiles for a gradually de-saturated hue. Although the creation of a 'saturation set' of tiles was considered, we decided not to include them in the activity. It was believed that the addition of these tiles would give too much information and usually it is better to leave the learners to make these connections in their minds as this can lead to deeper learning. Nevertheless, a smaller set of de-saturated hues could be introduced at the end of the activity to provide a visual reference to the term of *saturation* and the learners could be asked to guess their approximate position on the 3D shape to test whether they had made this link in their minds or not.

In order for the activity to work as a stand-alone application without requiring a tutor to guide the learners through the various tasks, a better introduction to the tasks has to be made and an example of a practical application of the concepts under investigation needs to be offered. For the purpose of this preliminary study, only the delivery of a selected limited topic had been tested. However, a number of additional colour theories need to be implemented in a similar tutoring style in order to have a more complete colour theory learning application. The learning activity did not cover many colour theories such as cool and warm colours, optical illusions, symbolism, cultural and historical connotations, etc. These could be included once the LBE method is defined.

One important thing that this study neglected to incorporate in the learner's trials was to offer some examples of how these colour theory concepts can be applied in everyday life and to give a reason why they might be useful to learn. Research suggests that learners are more motivated when they can see the usefulness of what they are learning and when they can use that information to do something (Lambert & McCombs, 1998). Likewise, skills are learned more effectively when the learner is aware of their need and has a personal interest in acquiring them (Bransford et al. 1999). For the learner trials conducted here this was not considered necessary and its omission was not expected to have any impact on the learning results (although it could probably have influenced the enjoyment ratings). It is however a feature that should definitely be included in future versions of the LBE method. Especially in Art and Design, students might not engage with a subject if they cannot see its usefulness or if they are not able to link it to their own practice. Examples of application of the acquired knowledge could be offered in the digital version as a link to 'further information'. Also, better connections among the various colour theories provided within a course should be made in order for learners to treat them as part of a wider knowledge area and not as individual cases.

8.3 The 'Learning by Exploration' Application

Here I discuss the benefits, drawbacks and implementation issues of the potential fully functional LBE software application for teaching the concept of HSV colour-space (not the

LBE-digital version that was tested here). For clarity this version will be referred to as 'LBE-application' to distinguish it from the LBE-digital version.

In theory, the LBE-application could be more flexible than the LBE-material version since it could be updated and altered much more rapidly and easily by a programmer than the cardboard materials. It would also be more portable as it could run on most computer systems. The physical model on the other hand needs a large carrier bag to be transported around and requires plenty of space, usually a large tabletop. In addition, after a number of tests, the cardboard began to bend and crush, and the coloured tiles started to fade from the touch, which of course *cannot* happen to the digital objects.

The study showed that participants reported enjoying 'playing' with the cardboard tiles because they could touch them. The tactile sense and the feeling of texture are important to most people. A simple computer screen is a single-sensory medium and does not offer this experience, but more advanced technology could. One easy solution would be to use touch-screens, while a more sophisticated one involves a VR system with special data-gloves that could allow the user to interact with the virtual objects by receiving tactile force-feedback. Of course the technology suggested here is not expected to be owned by students, but an institution could consider presenting such an activity through more advanced displays if available. Nevertheless, this finding was based entirely on personal preferences and it may not have an immediate effect on learning, thus further tests need to be conducted to see whether 'touch' has a significant impact on learning or not and whether it is worth the extra expenses when a simple computer might offer the same results.

Of course, if someone wished to replicate this learning activity to teach the HSV colour-space with physical objects, then it is possible to build them using more durable materials. But this was one colour theory topic and the spherical skeleton was feasible to construct. Other concepts may involve more complex shapes which may be impossible to replicate with physical material. In fact, Runge's colour sphere is one of many 3D colour systems that can be found in the literature. Although, the sphere served the purpose of introducing the relationships of the colour properties, more sophisticated colour systems which are being used in the industry nowadays, need to be raised in a colour course. Therefore, if a tutor wants to elaborate on this topic at a later stage, then a digital version of the LBE could be a better solution as he/she could have the option to choose which system to introduce to the students (e.g. RGB, CIE-Lab, NCS). In general, a digital learning resource could offer educators the flexibility to choose from a range of learning activities and thus create a course that fits the needs of their students.

After explaining the advantages of using a LBE-application as opposed to a material/human tutoring method, it is rational to discuss the feasibility of developing such as system. At the beginning of section 5 of this chapter the ‘Wizard of Oz’ technique was mentioned as a mechanism to conduct preliminary tests of computer applications by initially using a human tutor. It has to be noted that the trials were conducted by two researchers who had no formal training in tutoring this particular subject. Since no further information was provided to the learners apart from the prompts, it became evident that the proposed LBE process could be effectively conducted by a non-expert tutor, a fellow peer, or a computer; the latter being this study’s aspiration.

However, how can the human tutor's role be automated in the LBE-application? In essence, this would require:

a. *Making the user interface readily usable by novices.*

   This action could be done fairly easily by creating a 3D virtual environment with a user-friendly interface, interactive features and audio and textual means of communication. Usually such applications are developed through collaborations of programmers, who are specialised in 3D applications, and graphic / web designers or 3D modellers, who focus on the creation of the 3D models and graphics.

b. *Building in the tutor's prompts.*

   Since these were deliberately designed as a standard set, this should be unproblematic. The method of SQ was chosen with this in mind. The prompts served to highlight inconsistencies within the participants’ arrangements and to provoke reconsideration and thought of how these could be improved.

c. *Automating the tutor's choice of which prompt to select.*

   This would require the software to recognise features of the user's arrangement for each task (e.g. whether the cubes are organised in a straight line or a circle, which colour is at the beginning and the end of the line, which colour might not be between the correct neighbouring colours, etc). This is more difficult to integrate in the application as it would require the implementation of Artificial Intelligence. The computer could in theory be able to recognise a number of recurring arrangements and generate the appropriate prompts for each one. However, in the case of unexpected arrangements the computer could select a prompt that does not specify a colour’s position but that implies to the learner that this might not be the best way to arrange the cubes, without suggesting to him / her to organise them in a particular way.

d. *Capturing the learner’s self-explanations.*

   This may not be an essential feature to implement in the activity, but giving the learners the opportunity to externalise and explain their ideas has proven to be beneficial for deep learning (Chi et al. 1994). Furthermore, it increases engagement and interaction with the application by simulating a dialogue with the digital tutor. However, this feature is difficult to incorporate with the existing technology. The questions of how the learner's explanations could be captured (e.g. voice recognition software, inserting text, choosing from a list of potential answers) and how these are going to be used afterwards (e.g. by the tutor or the system to update the database), require further investigation in order to be answered.

A version of a LBE-application was never developed as I could not take its development further than stage (b) above. After this study was conducted I attempted to create at least the graphical environment for the activity. By using existing knowledge of 3D modelling, I could create all the 3D elements required for this exercise. During the second year of this research I also had the opportunity to attend some training sessions on EON Reality's EON Studio authoring software[29]. This software allows users to build simple interactive product content quickly and easily with no programming experience required. Therefore, I could program some basic interaction for the 3D elements. Nevertheless, even once this was complete, further development of the LBE-application required higher programming knowledge that I could not have mastered in a limited time. The innovative aspect of the learning activity was the LBE method which entails the use of suitable prompts. If the application was to be presented without this crucial feature then it would have fallen in the category of the other media or online based colour exercises. Hence, the development of the LBE-application could not be carried without the help of expert programmers.

9. Conclusions

The rationale for exploring the current state of colour education, and particularly colour theory courses, stemmed from an unpleasant personal learning experience. The literature and contextual review identified several educational problems with the way colour has been taught. It appears that teaching methods have not changed in the past 40 years and educators have been advocating the need for more updated and innovative teaching approaches. Furthermore, current changes in Art and Design institutions urge for more flexible, autonomous and remote learning that retain the ethos of studio-based practice, which is central in this discipline.

As a potential solution to the educational problem, this study proposed the use of an innovative 3D digital learning application for teaching the basic concepts of colour theory. The

[29] http://www.eonreality.com/products_studio.html

study focussed on the design, implementation and evaluation of the learning and teaching approach that was based on constructivist theories and Socratic questioning, namely the 'Learning by Exploration' (LBE) method. The preliminary trial, which involved 56 participants in total, assessed the method using a human tutor and material instead of digital objects. The educational topic of HSV colour-space was chosen for this learning exercise. The outcomes of the tutoring method were contrasted to learning from text. An experimental digital version of the LBE was also built to contrast the interaction with the physical and digital elements.

The analysis of the quantitative and qualitative data showed that the participants who were tutored with the LBE approach achieved deeper learning and understanding, and longer retention of the colour theory concept than those who were given the text version. The deep learning experienced by participants in the LBE condition was mainly due to a more effective teaching strategy that applied the selective use of Socratic questioning prompts. This encouraged the participants to construct ideas, elaborate on them, justify and integrate them with new ideas. This was consistent with the analysis of the problem based on educational theory. Moreover, there was no great difference between digital and material implementations of the LBE method, which demonstrated that further development of a digital application is worthwhile to gain the advantages of robustness and ease of distribution. A digital option could reduce the need for tutor interventions and allow students to use the third dimension more intuitively.

In light of the results and the observations carried out during the trial, the limitations of this first version were discussed in section 8.2 of this chapter and suggestions on how these might be resolved in order to refine the method have been offered. In addition, a theoretical framework of the steps that are required in order to develop the LBE-application was presented in section 8.3. For reasons related to knowledge and financial constrains, the LBE-application was not developed. Nevertheless, if an individual or an institution has the will and resources to develop this 3D application for teaching colour theory, this study provides the essential information for this purpose. In addition, the educational approach suggested in this study could be incorporated in most virtual learning environments that require students to conduct an exercise, whether related to colour or not. In general, the LBE method is a blend of various educational techniques that are most often applied in face-to-face tutorials. A number of digital learning applications could achieve greater learning outcomes by implementing a tutoring approach similar to the one developed in this study.

The idea to develop a way to facilitate learning and teaching of abstract colour theory concepts encompassed this study. It has to be stressed though that the practical colour workshop is important when dealing with the subject of colour. The theoretical part of the course could be offered either via lectures, handouts and books or via digital learning applications like the one described here. Further tests are needed once the application is ready to identify how it could best serve the needs of each colour course. Art and design students might be able to relate this teaching approach to existing studio-based learning and teaching and thus consider it familiar and engaging. Even though the LBE was designed with art students in mind, it proved to be effective with participants from various backgrounds and age groups. Therefore, the final application could also be used in secondary schools.

The literature review of colour education conducted for Study 1 identified another educational problem that mostly affects designers of the built environment such as interior designers and architects. The problems in learning and teaching in this area of Art and Design are due to the scale of the three-dimensional designs. Many educators have advocated the need for more effective colour education for interior design and architecture and some efforts to overcome these issues have been explored. The lessons learned from conducting Study 1 and the review of colour courses provided the idea and motivation to conduct a second study. The focus of Study 2 was directed towards interior design education, but the methodology and educational principles applied were similar to the first one. This follow-up study is presented in Chapter 5.

Chapter 5

Study 2: Colour Experience

How this study fits in the thesis

This chapter reports on my second study which designed and evaluated a 3D virtual environment on the subject of colour in interior design. The motivation for this study derived from the findings of the literature review conducted for Study 1. Through that investigation it became evident that courses related to the built environment such as architecture and interior design, encounter difficulties in learning and teaching the effects and use of colour. The problem primarily stems from the large scale of the projects and their three-dimensional nature. This study designed and evaluated a learning activity, which used a Virtual Reality environment, on the subject of *Colour Experience*. The educational objective of this activity was to raise awareness that colour can be subjective and that perceptions of how colour may influence mood or emotion in this area may vary greatly between people. The trial involved 20 2nd year interior design students and used open ended measures and observations.

1. The Topic: Colour Experience

Colour theory courses, of the kind conducted during the first year of a design degree in Art schools, mainly deal with rules of harmony and somewhat technical aspects of colour as opposed to psychological effects. These may include: terminology, colour schemes, mapping, gamut, additive and subtractive colour mixing etc. Yet another important aspect of colour is how it can affect people's moods, emotions and reactions, regardless of the visual medium (i.e. painting, poster, textile, film shown on TV, etc). For most of the aforementioned artefacts, the finished outcome can be viewed and as such the observer receives immediate visual stimulation from the applied colours (e.g. people might say that they like the combination of colours in a painting or a textile design), whereas in courses like interior design and architecture the finished outcome cannot be fully experienced as the design cannot be constructed in full scale. Hence it is difficult to predict how the colour scheme of an interior space or a building will influence the ambience of that space or what will be the 'subjective' experience of the occupants.

The term *Colour Experience* denotes the 'feeling' that colour can evoke and how this may affect people's moods. Thus, unlike dealing with the 'visible' aspects of colour (e.g. hue, saturation, value), which was the main focus of the first study (Chapter 4), this second investigation attempts to explore how the 'unseen' qualities of colour can be demonstrated given that they are not a matter for prediction and consensus.

People have personal experiences or inherent beliefs that certain colours can evoke specific emotions - these links are influenced by culture, age, gender, previous experiences, current trends and fashion. These beliefs can be persistent and therefore have a subliminal impact on the student's design decisions. However, the perception of colour depends greatly upon various parameters hence there is no simple and fixed set of links. So, even if students receive some sort of basic colour education this does not guarantee that they have grasped how colour can be used, in the field of interior design in particular, to evoke moods, highlight features, hide elements that otherwise cannot be removed, guide (i.e. to show the exit doors), etc.

1.1 Colour Emotion and Colour Preference Studies

Although this study deals with the issue of colour emotion and preference, it is not a colour emotion or colour preference study. Most of these kinds of studies involve experiments that are carried out under controlled laboratory settings (specific lighting and temperature conditions, background colour, distance between the viewer and the colour sample, etc.) Usually, the participants are asked to match the visual stimulus (colour samples of different hues or saturation) to an adjective (a list of words is often provided) that better describes what they felt after seeing the sample. These studies usually investigate the relationship between colour and human emotions, attitudes and preferences.

For example, Valdez & Mehrabian (1994) addressed the effects of colour on emotions and motivation and discovered that hue is less important than saturation and value in eliciting a response. Other researchers have investigated the emotions evoked by single colours (Ou et al. 2004a) and two-colour combinations (Ou et al. 2004b). Oberascher et al. (2005) have compared the emotional meaning of colours for different cultures, while da Pos & Green-Armytage (2007) have adopted a different method that matches facial expressions to colour emotions. Some experiments have explored colour emotion associations for interior environments; Banu Manav (2007) observed colour-emotion associations and end-users' colour preferences for residence interiors. She concluded that these associations are subjective and relate to personal like-dislikes, previous knowledge and experience – a finding that numerous colour researchers have found.

Most colour studies have predominantly used scientific quantitative methods to measure and analyse isolated properties of the perceived colours under controlled conditions, and although they provide precise data these can by no means be generalised or expected to be the same under different conditions and context. Westland et al. (2007, p. 14) argue that *'the recent scientific approaches seem to be increasingly disconnected from the context of art and design. Thus the preferences that are empirically determined in the laboratory may bear no resemblance to the preferences and choices made by art and design practitioners in the context of an expressive idea or in response to a design brief.'*

The colour emotion experiments that probably best relate to the use of colour and its effects on interior spaces or buildings are the ones that utilised a much larger coloured surface (a whole wall) or full scale rooms as opposed to colour chips. Maud Harleman's (2004) study used two full scale rooms with windows, one facing south and one north, and investigated the emotional impact of 13 selected colours on 90 observers. However, the difficulty to control conditions within a room or building and the element of subjectivity that governs humans, render the collection of reliable quantifiable results impossible, so even the results of studies that used full scale coloured surfaces cannot be generalised (Billger & Anter, 2006). Therefore, architects and interior designers should be aware that the outcomes of such experiments cannot be applied to any given design but should be treated as suggestions.

So the intention of this investigation was not to quantitatively evaluate the participants' reactions to the colours but to demonstrate to them that colour can affect the 'feeling' of a space. The intention was to provide the conditions to instigate a conversation regarding the emotions that various colour schemes can evoke. Therefore, the data collected here regarding colour emotion were used *only* to show how people's perceptions and experiences may differ. Conversely, this enquiry is an attempt to introduce a technology-based learning activity on the topic of colour experience in Art and Design education.

1.2 The Rationale behind the Selection of Interior Design

As mentioned previously, students of interior design and architecture courses cannot construct their projects in real-life size hence they cannot fully appreciate the impact of colour. Furthermore, for both these disciplines, colour plays a significant role in the design as it surrounds the occupants and thus has a strong impact on their psychology. Therefore, it deemed appropriate to design an educational activity, dealing with the effects of colour, either for interior design or architecture students[30].

Although architecture could have been a suitable candidate for this research, for practical reasons which relate to the size of the class (the number of students per year) and the scale of the projects (entire buildings or complexes of buildings as opposed to a single room, flat or store) I opted to conduct this study with the interior design department. Moreover, colour (as paint) is more frequently used in the interiors of the buildings rather than the exterior (where materials are more important) and its impact can be more prominent in a confined space than an open landscape. Additionally, in order to study the effects of a colour scheme on a building and how it blends with the surrounding elements, it is important to place the building within the environment it was destined for (i.e. a modern building inside the city, a cottage inside a forest and so on). Thus, for acquiring a better understanding of these effects, a 3D surrounding environment should be also created which in turn requires a more complex VE which obviously increases time for 3D modelling and programming.

2. How is Colour Taught in Interior Design?

Initially I was interested to find out how colour is taught in interior design at the Glasgow School of Art and elsewhere. What media do the students utilise to present their design ideas and how can the application of colour be studied through these media. Are they effective in terms of conveying the impact of a colour scheme on the ‘feeling’ of a space? What are the educational problems in this field?

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[30] Note that architecture courses also deal with interior design, mainly with the structural elements rather than furnishings and other decorative features hence graduate students can also work as interior designers. In general architecture courses are mostly offered through universities and polytechnics whereas interior design courses are often offered through Art and Design institutions. In some countries interior design is part of architecture. The Glasgow School of Art offers both architecture and interior design courses.

2.1 Basic Colour Courses

In most UK Art and Design schools courses on colour are offered during the first year or as part of the foundation programme and usually involve general colour theory and not subject-specific knowledge on colour application for different disciplines (e.g. interior design, textiles, ceramics, typography, graphic design, etc). Most often they are focussed on two-dimensional art such as painting and graphic design and include a number of practical exercises (Pile, 1997). As the content of these courses is generic, it seldom relates to colour use in interior design in particular.

To imagine how a colour scheme, solely chosen from colour swatches and samples, would work in a space and to foresee whether the intended mood will be successfully evoked, requires experience, intuition and understanding of all the parameters that influence the final outcome. Most young designers have not yet developed that skill. The appearance of colour in interior spaces is influenced by light, form, materials, textures, time, the external scenery and human context. A general colour theory course (as the ones presented in Chapter 4) does not deal with all these parameters in-depth, and more importantly it does not offer students the opportunity to experience how hues may change when viewed under different conditions through three-dimensional practical projects. Dohr & Portillo (1994, p.67) have asserted that *'Acquiring skills for systematically visualising colour in three dimensions and anticipating its complex effects enable students to better use colour in design. The reality of colour in a three dimensional context needs inquiry that is inclusive of, and sympathetic to, two dimensional colour theory, yet demands new ways of explaining and learning colour.'*

Therefore basic colour courses are insufficient for interior design students as the practical exercises are mostly performed in two-dimensions while their projects always deal with three-dimensions. This discipline could hence benefit from learning and teaching methods that offer students a more three-dimensional and immersive experience.

2.2 Colour Education in Interior Design: Courses and Methods

So, how do the disciplines of architecture and interior design deal with the subject of colour? What methods are the departments employing to teach colour use?

Before explaining how colour is taught in interior design it would be apt to mention the learning and teaching ethos of the course. Chapter 2 reviewed the various educational methods which are regularly encountered in Art and Design courses. Interior design is no exception; the course is studio-based and project-based with a high level of problem-finding philosophy as the designs should offer solutions for functional and aesthetically pleasing spaces. Students present their ideas to their tutors and their peers in 'crit' sessions and group tutorials. Most courses are delivered through practical workshops in the studio. Occasionally, professional designers will be invited to give a talk about their work. However, each department in each institution may have a slightly different educational approach, and the visualisation techniques may differ.

A brief investigation of the curricula of interior design and architecture courses, which are available on the institutions' websites, suggests that the majority offer a module on colour, usually during the first year of the course. Most publications on colour education refer to basic colour theory classes and only a few provide examples on how colour is taught within a specific discipline. More references are made to architectural curricula, which are easily transferable to interior design as both share common characteristics. One of the biggest differences with regards to learning and teaching approaches between these two disciplines is the number of students per year. Even though architecture assignments are also primarily project-based, the large number of students per year renders the incorporation of traditional lectures necessary. Therefore, architectural students may as well receive lectures on colour, potentially accompanied by a practical workshop. According to Anter (2008, p. 4) *'Colour and light seldom have any prominent place in architect's education, and the colours of architectural history are often forgotten or neglected. Thus the newly examined architect can often feel insecure if he or she abandons the stylised whiteness of the cardboard models'*.

A number of architecture tutors though have designed courses dedicated to the effects of colour and light (Minah, 2008; Unver, 2002; Linton, 2002, 1999; Oberascher, 2002). Prof. Harold Linton, who is now the Chairman of the department of Art and Visual Technology at George Mason University, USA, has authored 14 books on architecture, design, drawing and colour. Several of his published works have become adopted texts at universities and programs in higher education throughout the USA and Europe. His most well known books on colour are *Colour Consulting: a Survey of International Colour Design* (1991), *Colour Forecasting: a Survey of International Colour Marketing* (1994) and *Colour in Architecture: Design Methods for Buildings, Interiors, and Urban Spaces* (1999). At the College of Architecture and Design at Lawrence Technological University, Michigan, USA, the foundation design faculty has been utilising Linton's book *Colour Model Environments* (1985), to apply an approach to teaching colour that involves both two- and three-dimensional design experiences. Linton encourages interdisciplinary design dialogue by underlining the effective use of colour and light and asserts that the works of students, artists, designers, architects, and interior designers from around the world have become an important dimension in broadening the awareness of subjects areas of the course (Linton, 1991) (Figure 5.1).

Jean-Philippe Lenclos, who teaches the colour course at the National School for Decorative Arts in Paris, gives more emphasis on exercises that expose students to a vast array of dimensional situations. One of the tasks is to create structures within a cubic inner space by using only a scale of greys (Figure 5.2). Blacks, whites and greys become colour and rhythm, fulfilling their chromatic roles without the help of hues: depth phenomena and optic effects are based on clear-dark contrasts (Linton, 1991, p 161). Another activity of the course involves the creation of painted scales of colour value and chroma which can then be arranged in ways that give the illusion of dynamic spatial possibilities, going from a two-dimensional plane to a three-dimensional composition.

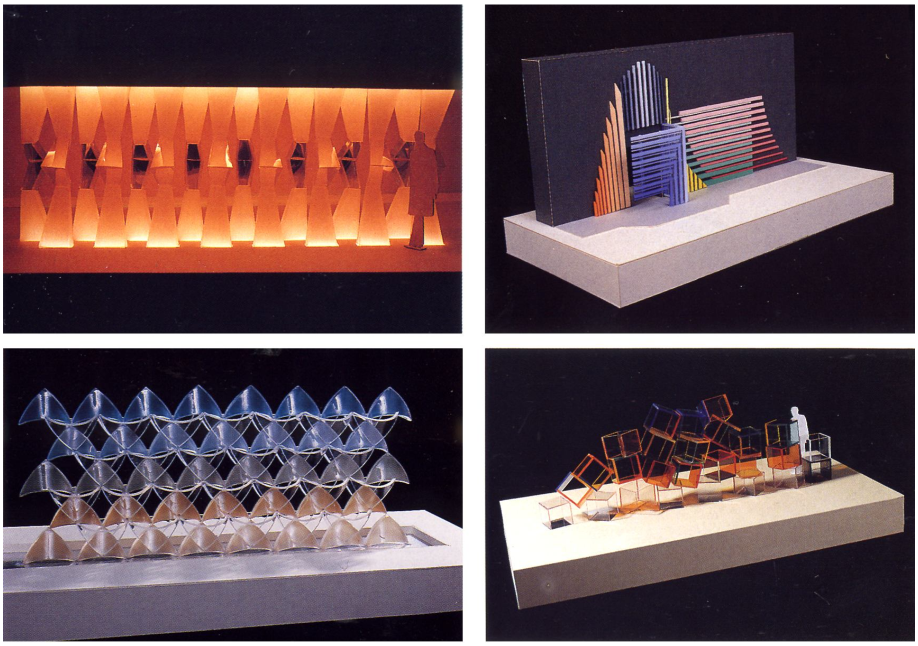


Figure 5.1: Student projects from the book Colour Model Environments by Harold Linton (1985)

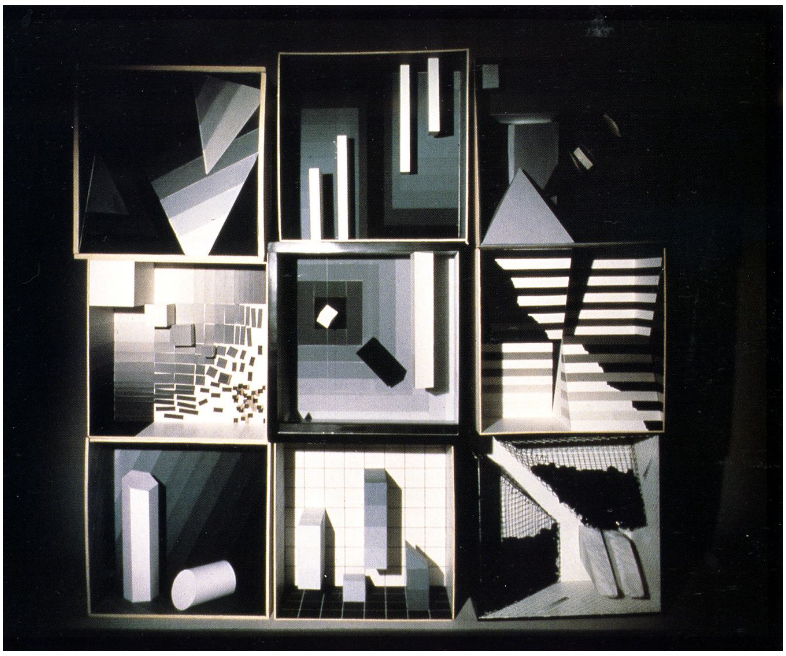


Figure 5.2: Three-dimensional achromatic, cubic studies of the course conducted by Jean-Philippe Lenclos.

Frank Mahnke is the president of the IACC (International Association of Colour Consultant/Designers) and the director of the IACC Education/Accreditation Programs conducted worldwide[31]. He is a lecturer on the psycho-physiological effects of colour, light and the human reaction to the built environment. In his book *Colour, Environment and Human Response* (1996) he advises on use of colour and light for specific purposes for a broad scope of environments, from hospitals to industrial workplaces. Two other academics who are specialised in the use of colour for designated interior spaces are Dr. Nancy Kwallek at the School of Architecture, University of Texas, Austin, USA, and Prof. Hilary Dalke at Faculty Art, Design and Architecture at Kingston University, London, UK. Kwallek has been studying the psychological effects of colour in the interior environment and the effects of colour on office workers' health, well-being, performance, and job satisfaction for over 15 years (Kwallek et al. 2007). Dalke is an expert in accessibility, sensory design and the healthcare sector and specialises in colour contrast for the built environment. Her published works concern the application of colour and light in hospitals, prisons and transport environments among others (Dalke et al. 2006).

Although descriptions and findings of research projects on colour application in architecture and interior design are available through books, journals and conference proceedings, no information about the way these researchers/lecturers are conducting the colour courses can be found as these details are rarely mentioned in publications. In the UK, a colour course, for which details were available, is conducted by Byron Mikellides (2006) at the Architecture department of Oxford Brookes University. The module is called *Psychology of Light and Colour* and is offered during the second semester. The course, through a series of lectures, deals with the biological, psycho-physiological and anthropological interpretations of the effects of colour and light.

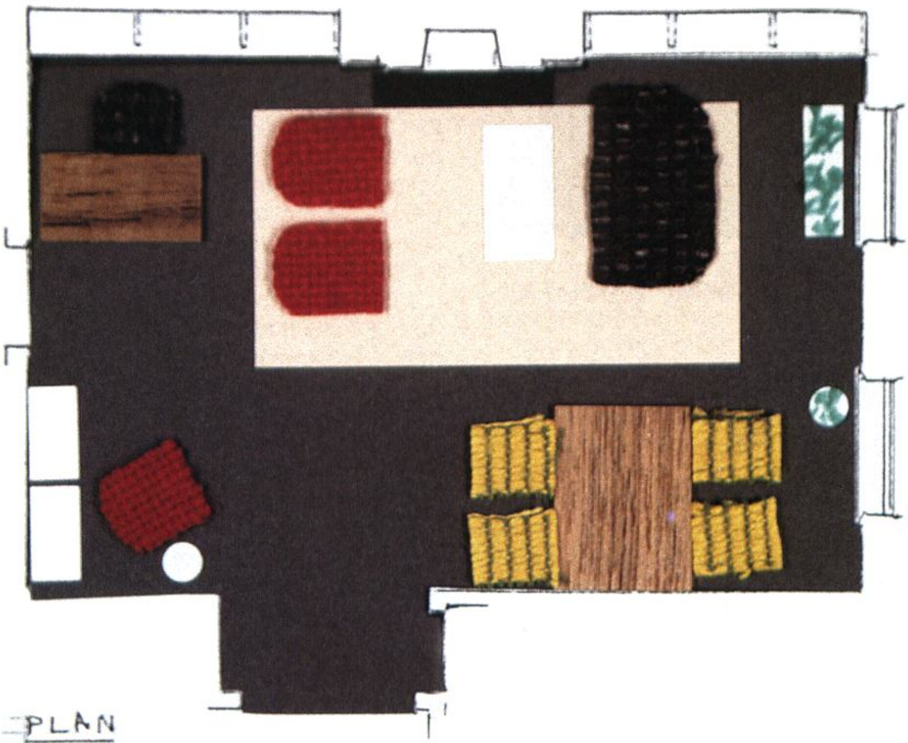
2.3 Methods Used for Creating and Visualising Colour Schemes

Most project assignments in interior design require the selection and application of a colour scheme. One simple and easy method for developing a colour scheme for an interior space is the creation of colour charts. These charts usually involve a collage of coloured papers, samples of actual material, paint colour sample chips, etc. A more refined version of such a chart is the plan colour chart; this uses the interior's floorplan as a guideline and the colour samples are cut out to match the exact elements of the interior (e.g. floors, rugs, furniture, etc.) Figure 5.3 shows examples of these methods. This method is problematic in the sense that vertical elements (i.e. walls) cannot be effectively presented. Therefore, in order to provide a more three-dimensional view of the interior, designers often create physical 3D

[31] http://www.iaccna.org/iacceducation/

small scale maquettes (mock-ups) that include samples of the colours and materials (Figure 5.4) (Pile, 1997). These small scale physical models are usually made out of cardboard, foam, plastic, Plexiglas, etc. Nevertheless, models of complex designs involving a lot of details and organic forms are very difficult to construct due to the limitations of the materials and / or poor model-making skills.

a



b

Figure 5.3: (a) An example of a detailed floor plan with colours indicated in locations where they will appear (b) Materials arranged in a floor-plan format

Figure 5.4: An example of a maquette colour presentation in which pieces of colour samples and materials have been placed in both floor plan and elevation locations.

One study which used cardboard model rooms as part of a colour learning activity was conducted at the School of Architecture at Chalmers University of Technology in Sweden (Billger, 2004). 280 architectural students, in groups of 3-5, experimented with a wide selection of surfaces, uniformly painted with several different hues and a few nuances to study the effects of colour and light. During and after the activity, the students wrote a report on the ways the colours affected each other and how light and colour interacted. They discussed different ways of interpreting spatial properties and the difference in experiencing the room from the 'outside'(looking at it through the opening) and from the 'inside'(sticking the head inside the cardboard model) (Figure 5.5). The agreement between perceptions of colour appearance was high, whereas perception of the spatial properties varied among students.

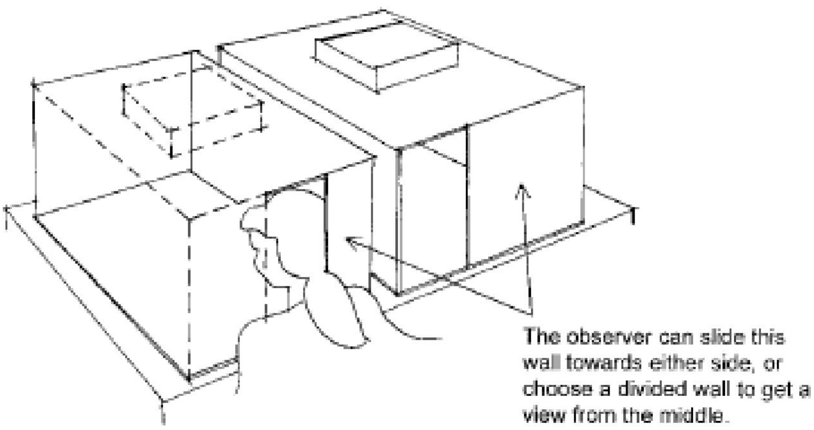


Figure 5.5: The image depicts the cardboard models used in Billger's study (1999)

Figure 5.6: A rendering of a 3D computer model with colours, textures and lights.

Nowadays most interior design departments are training students to use CAD and/or 3D modelling packages in order to create digital 3D models of their designs. Apart from modelling and modifying the structure of a space, the software also allows them easily to apply colour, materials and textures. After completing the 3D model they can produce renderings (still images) and walkthrough animations. A high quality 3D rendering can be seen in Figure 5.6.

Although both techniques (the 3D maquettes and 3D digital models) offer students the opportunity to visualise their designs in three dimensions, the digital method has more advantages: the students are able to make modifications easily and quickly and experiment with a plethora of materials available through the software. High quality 3D animations and print-outs can demonstrate a high level of realism with regards to colours, lighting, textures and reflections. The finished model can be viewed from different angles and distances; however the size of the visuals is obviously limited by the size of the computer screen, the printed paper or the projection area. Taking into account the fact that the size of the coloured area influences the way the colour is perceived it becomes evident that all the aforementioned visualisation methods, whether 2D or 3D, physical or digital, cannot fully simulate the real visual outcome. It must be reiterated that these methods cannot convey the impact that a colour scheme can have on the mood and feeling of a space primarily due to the small scale of the visuals.

3. Identify the Educational Problem

3.1 Why is Colour Education Important for Interior Designers

The selection of a successful colour scheme for an interior is the kind of knowledge that develops through experience. Unfortunately, there is no simple formula for using colour in architecture and interior design. Colour systems and suggested harmonious schemes do not guarantee successful use of colour (Sussman & Prejza, 1976)**.** Through practice the graduate students will gradually develop the ability to choose a colour scheme that is suitable for a given space by considering its size, form, use, occupants, etc. *'Obviously individual experience is invaluable, but learning by trial and error is usually expensive and the risks are often great. The feasibility of working consciously with colours, and to reach an intended result, is limited by our knowledge about how the appearance of coloured materials vary with context, that is how a coloured surface is affected by its spatial situation'* (Billger, 1999, p 230).

Billger (2004) argues that students need to understand the interplay between coloured surfaces and light, and how various colours within a room can influence each other. She also asserts that colour phenomena must be perceived before they can be understood and that is why she created the learning activity with the cardboard model rooms (described above): to make students aware of these spatial colour phenomena. The question here is how can undergraduate students gain experience on this matter through their studies.

Even though colour plays an important role in interior design it is often applied as an afterthought. Students are encouraged to work with colour from the very beginning of a project and experiment with it as they would do with shapes, forms, volumes, materials, textures, etc. According to John Gloag (1924, p. 87) *'Colour without its framework of form has no significance'*. He suggests that a balance between form and colour should achieve a better outcome and thus designers should always work with both these aspects simultaneously. Shashi Caan argues, however, that contemporary design education emphasises form over more intimate visual details and therefore *'is responsible for the present generation of designers who create tonal grey environments devoid of sufficient visual interest to enliven the human spirit, resulting in a discomforting sensory deprivation.'* (Caan, 1995, p. 152). It has been noticed that students prefer to work with the planning aspects of the design and its constructional details rather than making thoughtful decisions about the colour scheme (Pile, 1997). They tend to choose the colours only towards the final stages of the project, and therefore are reluctant to experiment with more unusual shades, especially when the deadline for the submission is approaching (Minah, 2008). Often, the students' 3D models seem to demonstrate rather effectively the intention and idea behind the design of the layout, but the motive behind the selection of colours is not always evident and sometimes not so carefully thought-out.

3.2 What Seems to be the Educational Problem?

The educational problem is primarily caused by practical and physical limitations. Esherick's (1976) view is that one cannot learn how to use colour only through isolated and abstract exercises but application of colour in real world cases is needed for observing the effects and receiving complete sensible feedback loops. Real life projects would be ideal for experimentation, and inarguably would allow young designers to try out, observe and assess the choice of colours under non-artificially made conditions. For example a project like that would entail students to design an interior for an existing space, whether this is located within the school's campus or in a building elsewhere that has been designated for this purpose. However, due to financial, spatial and time allotment issues, the construction of real full-size rooms within an Art and Design establishment is deemed unfeasible. In particular, the allocation of an open-plan interior space (designated for this purpose), the cost of materials and paints, the need for a specialist technician, as well as the time required for each student to construct their design in full-size, render this activity too expensive for an educational institution to manage.

4. The Proposed Solution

What would possibly support a more successful study of the effects of colour in interior spaces is a method that can offer students a more immersive experience, in other words, a method that could simulate real world cases. The idea of an immersive environment (physical or digital) has also been advocated by other researchers in the field of interior design and architecture. For instance, the cardboard box-like rooms (87x80x50 cm) in Billger's study (1999) allowed the viewers to stick their heads inside the model and observe the coloured surfaces, providing in this way a somewhat immersive experience (see Figure 5.5). Shashi Caan (Taraska & Makovsky, 2005) explores technological means of projecting an image of a space at full scale. She asserts that an immersive experience can provide a more holistic point of view when studying an interior design.

The department for Spatial Simulation at the Vienna University of Technology carried out a series of comparative studies involving physical full-scale modelling rooms. The studies, directed by Leonhard Oberascher, gave students and professionals the opportunity to use and compare different simulation techniques. Apart from computer-aided design, model endoscopy, stereophotography and holography visualisation techniques, the department has an experimental laboratory for full-scale modelling. In 1995-1996, in collaboration with students of architecture, they carried out five projects in which the appearance, effect, meaning, and functions of colour in architectural space were evaluated. A comparison between the different techniques of project visualisation and spatial simulation was also drawn (Linton, 1999, p 201). The experiments suggested that a definite advantage of full-scale modelling over other simulation techniques is that it permits realistic physical interaction between the user and the space. In turn, this allowed for better exploration, assessment and communication of the designs (Figure 5.7). A few years later Oberascher (2002) created *Luminos 3*, a mobile physical room (6x6x3.5m) made of 16 cells forming the walls. The user can alter the surface material and colour of the walls and study the effects while being immersed in the room.

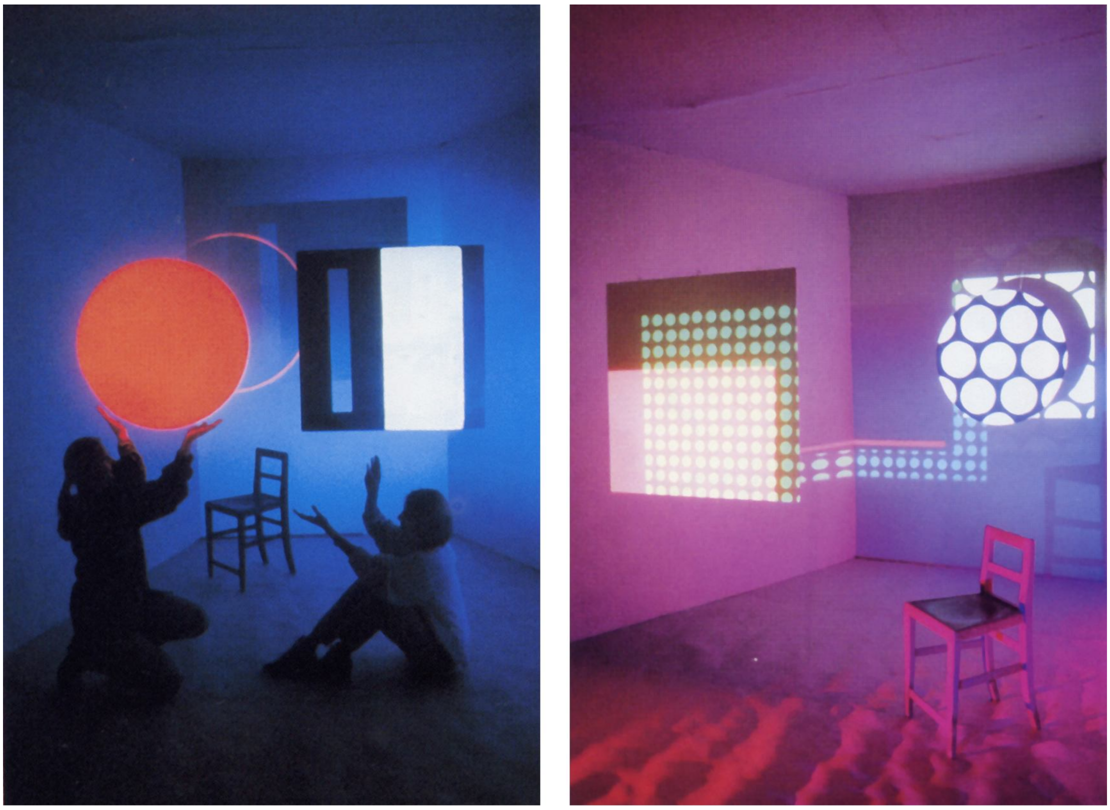


Figure 5.7: The photos show colour experiments within full scale modelling rooms. The experiments were directed by Leonhard Oberascher.

Recent experiments have explored the use of VR technology to study colour appearance and light simulation in interior spaces (Billger & d' Elia, 2002). This study focussed on the simulation of colour and light in VR from a technical point of view. No reports related to an educational evaluation of the system were found. Even though this type of technology has been utilised by architectural and interior design firms for presentation purposes mainly, it has not yet been extensively exploited as a learning medium in Art and Design education. A learning activity that uses an immersive virtual environment could potentially address some of the learning and teaching issues that this discipline has been encountering for many years and which the traditional methods presented above have failed to resolve. Linton (1999) believes that the use of immersive VR technology could offer great advantages to studying architectural spaces from the inside. Although the ability to simulate true colour may require further technological advances, *'the experience is profoundly better than seeing a computer graphics view on a small computer screen'* (Linton, 1999, p. 186). He believes that as the technology advances and display devices provide sharper, clearer image then VR will become an excellent tool for the colour designer.

During the discussions with the interior design tutors, the potential use of VR technology (a large 3D stereoscopic display) was discussed as it has the ability to give the viewers an immersive virtual experience. This, in theory, could reinforce current practice by projecting the students' designs in actual scale in an attempt to bring them one step closer to 'reality'. VR technology has advanced greatly over the last ten years so the graphics are not as crude and basic as the ones presented in the beginning of the 90s. Actually, nowadays, VR visuals have achieved a satisfactory level of realistic and model complexity. Apart from the appearance of the 3D models the most valuable asset of VR is that it offers the feeling of being engrossed in a real-size 3D model and the freedom to navigate inside it from an egocentric point of view. The aspiration of this study was to allow the students to experience their designs in almost life-size scale and so to give them the opportunity to draw their own conclusions about the colour choices from their immersive experience. The use of a VE provided via a VR display was envisaged as a mechanism for offering the students a full scale virtual representation of the designs that they cannot experience otherwise.

So, what can an immersive VE offer to interior design students? Can a VE address educational weaknesses that cannot be effectively resolved by conventional methods? To answer these questions a study was conducted in close collaboration with the interior design department at the GSA.

5. Designing the Learning Activity

This part of the chapter describes the strategy I pursued in order to design and evaluate the *Colour Experience* learning activity. All information collected regarding mood, emotion, beliefs and preferences was only used to demonstrate to students that there are similarities and differences in people's perception of colour. This study attempted to evaluate the impact of an immersive VE on a learning activity that focused on colour in interior spaces. The students were not formally assessed on this project as this was an experimental use of the 3D technology. The intervention was designed with the view to demonstrate the varied personal opinions, preferences and beliefs about colour rather than giving examples of successful colour combinations. So, the activity focused more on issues relating to human perception and psychology, which students need to consider when choosing colour for their designs. As such I opted for a qualitative evaluation approach that could gauge the students' responses with regards to the educational activity and the technology.

5.1 Educational Objectives

Some of the main issues are that the effect of a whole wall of colour is very different from the effect caused when the same shade is used on a poster, a small paper colour swatch, the computer's colour palette, in a font, or to distinguish the head of one pin from another. Therefore, the primary aim of this research was to examine whether students can gain a better understanding of the effects of colour in a room when the actual space is presented to them on a larger scale and particularly when they can be immersed in it. This intervention attempted to address a systematic weakness of interior design education and explore whether this type of educational activity can be implemented as part of the everyday studio learning and teaching.

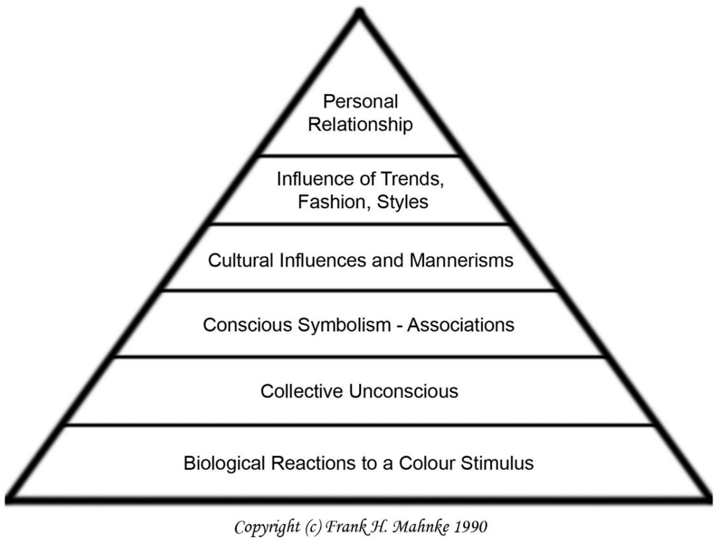


Figure 5.8: Frank Mahnke's *Colour Experience Pyramid*

Furthermore, interior design students must have a developed awareness that colour is a subjective sensation that can affect the mood and feeling of a space and consequently the psychology of the occupants. People have personal experiences and inherent beliefs that certain colours can evoke specific emotions - some of these links are also associated with culture, age, gender and current trends. For instance, Mahnke (1996) provides a diagram, namely *Colour Experience Pyramid* (Figure 5.8) that shows six basic interrelated factors that influence our experience of colour.

Typically, associations with colours (e.g. green with nature, red with anger) lead to stereotypical attitudes towards the use of colours and these should be subdued (just like many stereotypes) (Odom & Sholtz, 2000). A designer should be aware of and responsive to such issues, which he/she will face when working with clients or even other designers. Hence, a second, yet equally important, learning objective of this educational activity was not to teach facts but to raise awareness: to make the learner appreciate that it is important that opinions in this area commonly differ.

In the design of this educational intervention, I originally had several learning aims in mind, all relevant to interior design students. These are listed below:

1. Hues are perceived differently depending on the size of the coloured area; thus we perceive a hue differently if it covers a whole wall than if it is a small dot. That is the reason why many people have trouble selecting paint for a wall on the basis of colour sample cards.
2. A colour's appearance is affected by nearby colours: for instance when two different shades on adjacent walls meet at a corner of a room (simultaneous contrast).
3. The colours of a room can have an effect on people's psychology. This link between colour and feeling, however, varies greatly between people, including between people from similar social backgrounds on the same course at the same institution (Itten, 2002), generally the tutors expect everyone to have a similar response. It is important for interior designers to realise that their own perceptions will often not be shared by others, including their clients and colleagues.

I decided to focus mainly on the first and third of these learning aims: on the fact that the scale/size of the coloured area influences perception of colour and on how colour influences people's mood. The intention was to replicate the real size of a room/interior space by using an immersive display in order to allow the students to experience their colour choices on a bigger scale, to view each other's models and to generate a discussion about the feeling that each room generated.

The reason I did not proceed with the second learning objective was basically due to technical limitations. This particular learning objective would require a photorealistic VE which obviously requires more time for programming the reflections, refractions, radiosity, caustics, shadows, etc. as it is necessary to 'fake' these colour interactions within the software as they do not happen naturally as in the real world (e.g. in real life a green glass when hit by a light will cast a green shadow on a white surface and not a black/grey). Hence, due to time, cost and technological limitations a photorealistic VE could not have been realised. In addition, the focus of this research was not to create a VE that simulates realistic colour appearance but to evaluate its impact as an educational medium. However, the best way to study this phenomenon is through real-life physical spaces. Billger's experiment involving the small scale cardboard models was designed with this learning objective in mind (Billger, 2004).

5.2 Educational Theories

Educationally, this learning activity is in strong contrast to teaching aspects of colour for which there is almost complete consensus and a detailed scientific account (as the ones presented in the Study 1). The strongest consensus is between people who are shown a range of shades of colour and asked, for instance, which is the most prototypical or 'reddest' red (Berlin & Kay, 1969). Dealing with colour-feeling associations is similar to dealing with the counterpart in colour education of critical thinking (Kuhn, 1991). The primary educational objective here is to overcome the students' naive belief that there is a single right answer, that everyone thinks and acts in a similar manner (Perry, 1968), allowing them to realise that their own view is one of a number of equally tenable views. Basic colour education is the first step to cultivate students' subjective attitudes towards colour. More specialised colour courses could improve students' visual thinking and reasoning, and thus transform their naïve and subjective responses into objective and analytical approaches.

Considering the constructivist nature of current learning and teaching methods within the discipline, it was important to base the design of this activity on analogous educational methods. Therefore the activity was designed to offer learners a space for experimentation and reflection. General educational principles of particular importance for this topic were constructivism, in the sense of getting learners to link the topic to their own personal experience and perceptions, and peer discussion to demonstrate how much variation in perceptual experience and judgment there is between people.

5.3 Participants

Before designing the learning activity it was also important to identify the group of learners who would participate in this study. The head of the interior design department suggested that the 2nd year students could benefit more from this experiment. Workshops on a 3D software package (VectorWorks[32]) had just begun for the 2nd year students therefore it was deemed appropriate to combine this with the VR activity. Usually, during the first month, the students learn the basic tools and familiarise themselves with the 3D software. After this period the tutors assign them a couple of small projects (e.g. to build a simple room using the software). The interior design tutors were keen to exploit the immersive ability of a VR

[32] http://www.vectorworks.uk.com/vw/index.jsp

display and combine this experiment with the existing workshops. Hence the idea was to incorporate the VR learning activity as seamlessly as possible into their existing schedule but not as part of their assessed projects.

Twenty 2nd year students of the interior design department at the GSA participated in this study. At the GSA, design students do a four-year degree program, of which the first year is general, while in the second year they are regrouped on a subject specific basis to join one of the five specialisms of which interior design is one. Students who have completed the first year in another institution or even another country can also be admitted into the second year. Therefore 2nd year students do not know each other well at the start of this year (this issue is raised here because the group dynamics played an important role during the group discussions that took place towards the end of the trial). Note that these students' cultural backgrounds also varied and therefore their beliefs about the associations of colours may vary as well.

My role as a researcher in this study was to meet with the interior design students, either individually or in groups, and conduct the tasks described further down in the design of the trial. After the trials, I also interviewed the participants. Even though the head and the tutors of the interior design department were consulted at the beginning of the study in order to specify the content of the learning activity and thereafter to create the student groups and timetable, they did not take part in the study nor as participants or as researchers. However, for the creation of the interactive VEs the help of an experienced 3D programmer was necessary.

5.4 The 3D Model

The intention was to align the trial with the course's teaching programme and consequently combine it with a current project assignment, therefore I utilised a 3D model of a room that resembled the one that the students have been working on for the term's project and were thus familiar with. Hence the shape, size and elements of that room had been defined by the tutors who provided the model in CAD format. A plan and a perspective view of the 3D room can be seen in Figure 5.9.

At first the option of students selecting some 3D objects from a custom library of ready models such as furniture, lamps, rugs and glass panels, and dragging them into the 3D scene was discussed. This library would also provide a choice of textures and fabrics rather than applying only plain colours on matt or shinny surfaces. However, in discussion with the tutors, we agreed to focus the activity on the application of colours as paints on the interior's surfaces and not to include materials and textures which could possibly detract learners from the main task. The colour palette used in the study is discussed in the following section.

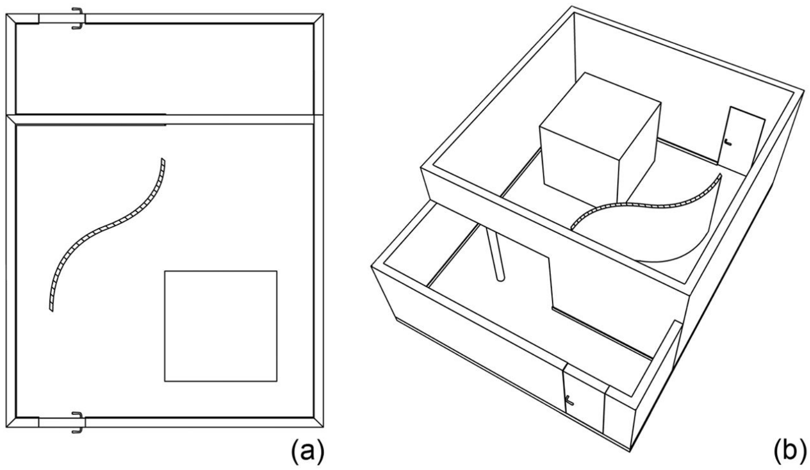


Figure 5.9: The room's floor plan (a) top view (b) perspective view

Additionally, the idea to program some interactions within the 3D space in order to retain the students engaged in each room was raised (e.g. asking students to pick up an object and place it on a predefined position). However, the completion of specific tasks within the VE was not considered essential for the current educational activity hence only the action of opening and closing the doors of each room was implemented.

5.5 The Colour Palette

Instead of using the colour palette of the 3D software, which offers millions of colours, for the purposes of this experiment I created a custom one (Figure 5.10). It was agreed that the palette should include pure colours (i.e. fully saturated hues such as red) as well as a tint and a shade of that colour (e.g. pink, burgundy red). The brief that was handed to the students during the first stage of the study stated the number of colours that should be used (5 colours including tone variations). The palette comprised of 21 colours including the achromatic black, grey and white.

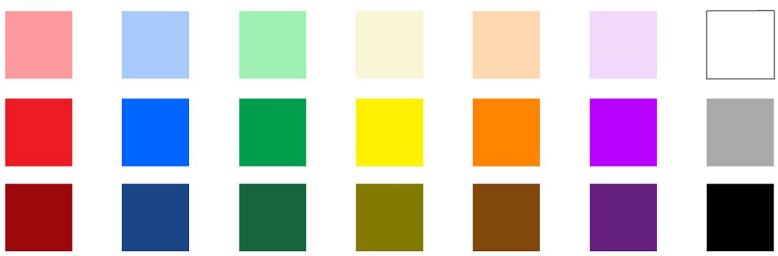


Figure 5.10: The Colour Palette

The reason for using such a limited palette was twofold. First, this allowed better control over the trial. The palette was created using a 2D image processing software (Adobe Photoshop) and was printed on high-quality paper in order to achieve less divergence between the printed palette and the screen colours. The RGB (red, green and blue) fields of each hue were recorded so as to generate the same hues within the 3D software. Creating five different hues for each student (approximately 100 hues) would have been very time-consuming and variations of colour tonality between a computer screen and the VR display would have been more noticeable and difficult to control. Second, the selection of pure colours such as red, blue, yellow, orange, purple and green it was anticipated to demonstrate whether the students' beliefs about the associations of colours with certain emotions had influenced their design decisions. Moreover, selecting colours from a limited palette would inevitably produce some similar colour schemes; however what was important to raise here was that a different feeling could be evoked by using the same colour scheme in a different way. This was expected to lay the ground for the group discussion and to challenge these stereotypes.

5.6 The Technology: The Semi-immersive VR Display

The trials were conducted using a semi-immersive VR display. The virtual rooms were projected on a 1.8x1.3m wide screen through an active stereo CRT projector positioned at the back of the screen. The students had to wear Crystal Eyes stereo goggles, which produce the depth perception by separating the image for left / right eyes. The 3D rooms were displayed using an existing virtual reality toolkit (VEGA) that enables rapid application development. The system was driven by a standard high-performance PC. Note that the application is configurable to suit a large range of presentation systems, from a laptop computer up to fully immersive environments such as a CAVE (Cruz-Neira et al, 1993) and could easily be used with a portable projection system.

The users have an egocentric view (first-person point of view) of the environment and can navigate inside the 3D rooms by using a conventional joystick. Although more sophisticated input devices were available, the 3D programmer and I decided to use a joystick as most people are already familiar with it from previous gaming experience. A terrain following constraint maintains the position of the user at the proper height above the floor of the virtual world while the joystick enables him / her to explore the space by moving and looking in all directions. Further constrains have been added to the model's surfaces to restrain the user from passing through walls and doors. Apart from the 3D model no other elements (i.e. menus, bars and buttons) have been projected on the screen so as to keep the interface as unobtrusive as possible.

Even though the environment supports a multi-user experience (more than one user viewing the display simultaneously) the navigation can only be controlled by one user at a time. The specific VR set-up might not offer full immersion into the virtual world such as a

CAVE, it gives nonetheless the impression of being engrossed in a real-size virtual room. Additionally, navigation within the VE and the interaction of opening and closing doors, gave the students a strong sense of participation and movement within the space. Unlike animations, students can make decisions as to where to go, where to look or when to pause in the VE, which gives them better control over the experience. In reality, the user remains (relatively) still while the VE is moving around him / her.

5.7 The Structure of the Study

The VR facility is hosted at the Digital Design Studio (DDS), which is part of the GSA but located away from the main campus. Hence, in order for the students to use the VR display, they had to travel from the main campus to the DDS. Therefore, due to the distance between locations, the learning activity, for practical reasons, had to be conducted in two sessions: one that took place at the interior design department and one at the DDS. Below is an outline of the two sessions and the various stages involved; each stage will be further described in turn.

- **a. First Session** (Interior design department – one-to-one sessions)
  1. Introduction of the task. Students to select a colour scheme for the interior.
  2. Application of the colours on the 3D computer model using a laptop computer.
- **b. Second Session** (DDS – 4 groups of 5 students)
  1. Reminder of the colour choices. Students to answer a brief questionnaire about the feeling they intended to evoke and about colour-emotion associations.
  2. Students to explore the 3D rooms using the VR display.
  3. Students to answer a follow-up questionnaire about their approach towards colour and then share their views about the colour schemes with their peers in a group discussion.

5.7.1 First session

The first session took place at the interior design department.

Stage 1: *Introduction of the task. Students to select a colour scheme for the interior.*
Initially, the students were given a brief that described the activity, a plan and a perspective view of the room on an A4 paper and the printed colour palette (Appendix B). The brief prompted them to choose a colour scheme for the room which was (theoretically) situated within a larger office complex. Although the brief mentioned that this was a public space, the room was not given a particular function. The reason for not specifying the use of the space was twofold: first we wanted to allow more experimentation with colours and second we believed that a flexible and open brief would produce more diversity in colour choices and so more varied experiences.

The students were asked to choose five colours from the palette and apply them as they wished on the walls and the other surfaces (e.g. floor, ceiling, doors, panels, skirting, etc) of the interior. The only condition was that three of the five colours should be selected from the same row (e.g. pink-red-burgundy red, black and light purple). The paper depicting the floor plan was used to note down the codes of the colours and to point out on which surface they should be applied. They were also asked to optionally provide a rationale for their colour scheme choice and application. They were given one hour to complete the task.

Stage 2: *Application of the colours on the 3Dcomputer model using a laptop.*

After finishing the task, I met with each of the students individually and together we applied the selected colours on the digital 3D model on a 17" screen laptop PC. As mentioned previously the colour palette had been recreated within the 3D software in order to ease application of the same colours on the model. At that stage the students had the opportunity to see the room from different angles since they could manipulate the model within the software (i.e. rotate, pan, zoom). Certain students realised that some of the colours they had chosen were either too dark or too intense when applied on to larger surfaces, and as such they slightly altered their initial design.

The majority provided a rationale for their colour choice explaining why they had selected these five colours and what their intention was. Some were more experimental than others by creating very contrasting combinations, applying different colours on different parts of one wall and painting the floor and ceiling with very dark or very light hues. Although they were aware that certain colours would create a strong visual impact they decided not to change their design because they were interested to see how it would look on a larger scale on the VR display. One student also used the colours to create a linear pattern and applied it on a whole surface. The students' responses are presented and discussed in section 6.2.1.2.

5.7.2 Second session

This session took place two weeks after the first session at the DDS where the VR facility is hosted. The students travelled to the DDS in four groups of five. Each group had been allocated 2 hours and 30 minutes, so the sessions were conducted in two full days (morning and afternoon) as seen in Table 5.1.

Stage 1: *Reminder of the colour choices. Students to answer a brief questionnaire about the feeling they intended to evoke and colour-emotion associations.*

At the start of the second session each student was handed an image of a perspective view of his/her coloured interior and a chart with the chosen colours (Appendix B). This served as a reminder of the colours they had selected during the first session. They were asked to write down their answers to the following questions:

Table 5.1: The table shows the times that the four groups of students visited the DDS.

DDS - Day 1	DDS - Day 2
Group 1 Morning (10:00 – 12:30)	**Group 3** Morning (10:00 – 12:30)
Group 2 Afternoon (14:30 – 16:00)	**Group 4** Afternoon (14:30 – 16:00)

1. *Do you believe that certain colours are associated with certain emotions?*

   This question was asked in order to gauge each student's beliefs on this matter and to see whether their views were influenced by existing stereotypes. This also provided an indication of their understanding of colour and awareness of the various factors that can influence colour perception.

2. *What sort of feeling do you expect your interior will produce?*

   The answers to this question were used during the group discussion (final stage of the second session). The intention was to contrast the intended feeling of an interior (the mood that the designer had intended to evoke) with what the participants (including the designer) actually felt while inside that interior. This comparison provided some interesting points for discussion as sometimes the intended and the evoked feeling were aligned, whereas in other occasions they were contrasting. This activity demonstrated that colour can be subjective and therefore can prime different emotions in each individual.

Stage 2: *Students to explore the VR rooms.*

This stage of the activity involved students experiencing the interior rooms using the semi-immersive VR display (Figure 5.11). The students viewed the rooms in groups of five. All the students were given the opportunity to navigate inside an interior, which was chosen at random (this could be another student's room or their own). Note that before exploring the coloured rooms, each student walked inside a similar VE, with no colours. This served as 'the training room' and was used to introduce the technology and the navigation controls.

In order to offer both a personal as well as a shared immersive experience, each student viewed his/her own room and also four other learners' rooms. The five students' 3D rooms, had to exist in the same VE and consequently in the same executable file and have some sort of realistic connection between them. Therefore, the original 3D room was copied five times and each room was placed adjacent to the other (two of the rooms had been rotated 180 degrees to give the sense of randomness). A model of a neutral-coloured corridor was built and attached to both sides of the rooms (a view of the five rooms and the two corridors is provided in Figure 5.12).

Figure 5.11: Participants exploring one of the 3D rooms

This design allowed students to begin the exploration from a neutrally coloured space. After randomly choosing which door to open, the students could enter a room, navigate inside it and exit it by using the other door. All five rooms could be revisited at any time without having to stop the simulation or loading a new file. Apart from connecting the rooms, the corridors also served as spaces where participants could 'rest their eyes' as the neutral colour did not evoke strong visual stimulations.

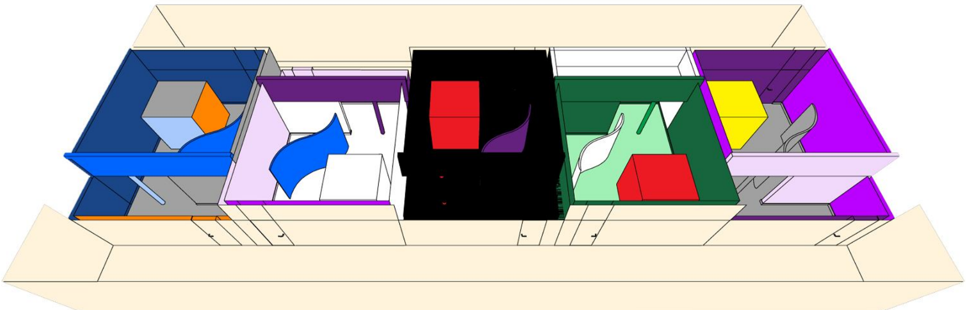


Figure 5.12: A view of the layout: five rooms and two corridors

The sequence of viewing the rooms was random. The doors of the rooms were closed so the students could not recognise which one was their own. After having viewed a room, the simulation was paused and the students were asked to write down three words that better described the feeling of the interior they had just experienced. In addition, they were given a simple emotion scale (Table 5.2) which prompted them to circle the numbers on a scale from 1 to 5 (3 signifying neutral); this provided an indication of whether that feeling was positive, neutral or negative.

It is not always easy to instantly generate three words that describe the feeling of a space or an emotion, therefore the emotion scale played a supporting and complementary role in helping students to describe their experience. The comparison of the learners' scales actually offered the average feeling (positive or negative) of each room. This thereafter became the central topic of the group discussion.

Table 5.2: The emotion scale gave an indication of how positive, neutral or negative was the feeling of each colour scheme.

Question: For each pair of emotions below, please circle the number on the scale which most closely corresponds to your emotions while in the room (3 being neither strongly one nor the other).		
Comfortable	1 2 3 4 5	Alert
Relaxed / Calm	1 2 3 4 5	Insecure / Disorientated
Surprised / Excited	1 2 3 4 5	Annoyed / Anxious
Happy	1 2 3 4 5	Depressed / Melancholic

Stage 3: *Students to answer a follow-up questionnaire about their approach towards colour and then share their views with their peers in a group discussion.*

After the VR experience, the participants gathered back again in the meeting room where they were given a new set of questions (Appendix B). This questionnaire served three purposes: first to give the time to the researcher to write down (on a flip chart or whiteboard) the intended and the evoked feelings, to place the students' marks on the emotion scales and to prepare for the discussion. Second, these questions were raised again during the discussion hence the questionnaire allowed students the time for reflection and preparation. The third reason for the existence of this questionnaire was to keep a record of the students' answers and thoughts without the need of audio visual equipment.

The questions were:

1. *How important is colour in your work?*

This question aimed to get an indication of the learners' views about colour in interior design and most specifically in their own work. The idea was to encourage students to reflect on their personal practice and experience.

2. *Do you normally use colour for aesthetic or practical reasons?*

This topic was raised to allow students to think of how colour can be used for practical reasons as this would be analysed further during the group discussion. The replies also indicated whether the learner had a more profound understanding of the use of colour within the discipline of interior design.

3. *When you are choosing a colour scheme for an interior what are your main considerations?*

This question initially intended to generate a dialogue about the factors that can influence the appearance and perception of colour, and other considerations such as the importance of the client's preferences, the function of the space, the size, the form, the textures, style and trends, cultural beliefs, etc.

4. *Was the visual impact of the chosen colours different when viewed on paper, on the laptop screen and in the VE?*

This question prompted students to think of the three media (paper, laptop screen and VR) and discuss whether and why the same colours appeared different and how much the size of the display area affected the colour's appearance, its relationship to neighbouring colours and the overall feeling of the interior. It also gave an indication on how the students had perceived the size of the room.

The purpose of the group discussion was to provide an opportunity for the students to comment on the VR experience and the colour learning activity as a whole, and to voice their opinions about the colour schemes. The comparison between the intended and evoked feeling and the results from the emotion scales provided the ground for initiating a debate regarding the subjective nature of colour.

6. The Study

6.1 The Pilot

A week prior to the actual trial a pilot study was conducted with five participants[33] in order to:

- *Determine whether five students was an appropriate group size for the particular learning activity and the time spent inside the VE.*

As presented previously, this semi-immersive VR system supports multi-user experience which means that more than one user can view the VE simultaneously. The ideal number of viewers for each VR setup varies as it depends on numerous parameters. The number of viewers for the particular display is limited by two issues: the size of the physical space in front of the big screen and the number of 3D goggles available. As these glasses are stereo active and not passive (like the ones used in IMAX theatres) their purchase and maintenance cost is quite high. The DDS at the time of the experiments had seven 3D goggles available so in theory we could have divided the 2nd year class into three groups of seven. Nevertheless, this would entail the researcher not wearing glasses and additionally if one pair of glasses presented a

[33] These five participants were students of a 3D animation Masters course at the DDS.

malfunction one of the students would have been unable to view the VR display properly. Hence it was decided to create four groups of five students which also allowed the researcher to view the rooms and also to keep a back-up pair of glasses in case a problem arose.

Furthermore, a bigger group of students would have also entailed spending more time inside the VR facility and often that can be strenuous as it may cause eye strain and dizziness. Therefore, one of the purposes of the pilot trial was to test whether the time spent inside the VE was acceptable and comfortable for the participants. The pilot demonstrated that five participants were a reasonable size group in terms of group dynamics and time required to explore the virtual rooms.

- *Test the questionnaires*

  Before the pilot, the questionnaires were given to two colleagues, who have experience in conducting user tests, so as to identify any problems with the language and structure. As the pilot's participants were not drawn from interior design, it was expected that they might have difficulties relating some of the questions to their own practice; nevertheless this did not seem to be an issue.

- *Estimate the time spent for each stage.*

  This information informed the final time schedule for the visits to the interior design department and the DDS.

- *Identify any potential problems with the equipment (joystick, 3D glasses) and the setup of the room and try out the procedure overall.*

  The pilot trial also offered the opportunity to try out all the stages of the learning activity. It served as a rehearsal for the researcher on how to keep participants focused, how to visualise the emotion scales on the flip-chart so as to be comprehensible for the students and how to instigate and steer the group discussion.

The pilot trial ran smoothly and no critical problems were discerned.

6.2 The Learner Trials

In this section I will present, in more detail, the participants' responses to the different tasks, provide quotes from the questionnaires and share my observation notes. Two months after the experiment, the participants were interviewed individually to gauge their comments and feedback regarding the learning activity and the technology used in the trial. The interviews are presented in section 6.3.

6.2.1 The first session

The students were handed the brief for the task along with the consent form (Appendix B) and were allowed one hour to complete the task. When a student felt that had finished the task he/she met with me and together we applied the colours on the 3D model. At this stage the students did not yet have a clear understanding of the purpose of the activity given that it was not similar to what they were normally doing in the studio. One of their first questions was whether they would be assessed for this activity. I, and their tutors assured them that this task was not be formally assessed therefore they should feel free to be experimental. On hearing that the participants seemed all quite enthusiastic to try out the colours as they were keen to see how they would look on a larger display.

6.2.1.1 Colour selection

The reason for not providing a greater time scale for the completion of the task was mainly because we were hoping for a spontaneous response to the brief. The colour palette included intense and bold colours, which normally would not have been among the students' top choices. They were told that they could apply colours to all the surfaces of the room including the ceiling and the floor.

Interestingly, the most selected colours were the purple tones and the achromatic white, grey and black, whereas only one student chose the green row. Some designs were too dark, others too bright, while most used contrasting colours. Only one student used all five colours to create a stripy pattern for the curved panel.

6.2.1.2 The intention behind the selected colour scheme

At the back of the third sheet, the students were prompted to note down what was their reason for choosing a particular colour scheme. The motives varied; some followed colour harmony rules while others were inspired by the forms inside the space or the work of other designers. Some examples are offered below:

> *'As the space is for general use I decided to use warm complementary colours, which have energy without creating an overtly colourful interior.'* IDS7

> *'Vibrant colours working with soft pastel colours. A play between contrast and colour temperature.'* IDS1

> *'I wanted to create a calm space with bold and strong geometric shapes placed within it. This space shows a strong relationship between two complementary colours: green and red. I have chosen white to emphasise the relationship between these complementary colours.'* IDS15

'I chose a bright entrance area to contrast a darker interior. The door colours contrast the walls they are on to stand out. The interior is meant to be dramatic.' IDS12

The above quotes show that some students used complementary colours in order to create high contrasts and a balance between warm and cool tones. This approach demonstrated an application of colour theory knowledge to create a harmonious, balanced or high contrast visual effect.

'I chose the Y3 to maybe make the space warmer as there's no natural light and also to make it appear larger.' IDS16

This student's intention was to change the physical properties of the space by selecting colours that could make it appear warmer and larger.

'The curved wall made me think of a wave which made me think of the ocean hence the shades of blue. The plain, white walls are to bring out and emphasise the blue. The block made me think of a boulder hence it being grey.' IDS19

This participant's colour scheme was obviously inspired by the forms present within the room (i.e. the curved panel, the big cube). He associated the forms with elements and hence he opted for colours that would be apt for them (i.e. blue for the wave, grey for the boulder).

'Using predominantly white throughout the main room gives an opportunity to "frame" the box and curved wall. Bold colours have been used on these objects, again framing these shapes, making them stand out more.' IDS13

Similarly the above student used colour in order to make the features of the room stand out.

'My idea is a little inspired by Philippe Starck. I will just play with the colours and experiment on the computer. I'm not really sure what is going to be like.' IDS18

This learner drew inspiration from the work of a famous designer. However, she was unsure of how the colours would look on large surfaces. This participant's design was extreme and dark but she decided to keep it as such in order to see the effects of the colour scheme in the immersive VE.

From the replies it became apparent that some students had a clear idea in mind, whereas others just choose their favourite colours. Most of them hoped to create a comfortable and pleasant interior that would appeal to most people regardless of age, gender and nationality. Conversely, a few learners exploited this opportunity to create a 'weird' scheme so they could view its effects on the VR display. Although the latter is not considered as a thoughtful approach to colour use, for this experiment it was quite beneficial as it produced a wide variety of coloured interiors. Appendix B shows all the student's coloured interiors.

6.2.2 The second session

The second session of the learning activity was conducted at the DDS. The schedule of the visits can be seen in Table 5.1 above. Transportation to and from the DDS was arranged for the students; however, six students could not attend the trial either due to illness or due to time clash with their work schedule. Even though the students and their tutors had been informed that they could swap places with someone else if they could not attend the session they were assigned to, only two students swapped places. Unfortunately, a date for an additional trial for these six students could not be arranged as after the actual trial the room that hosts the VR display had to undergo sound-treatment work for two months. This was considered a long period of time for students to remember what they had done during the first phase of the activity, hence the trial was not scheduled.

6.2.2.1 Responses to the first questionnaire

When the groups of students first came to the DDS they were led to the seminar room where they were briefed about the different stages of the activity. They were handed an A4 sheet which contained an image of their interior (perspective view), which served as a reminder, and two open-ended questions. The answers to each question are provided and discussed below.

> **Question 1:** *Do you believe that certain colours are associated with certain emotions? Can you provide an example?*

Three categories of approaches were discernible: one that is more inclined towards stereotypes, one that acknowledges that colour perception can be influenced by other aspects such as culture, previous experience and environmental conditions, and one that is more related to the student's design style.

a. *Stereotype-oriented approach*

> *'Yes, I believe that certain colours are associated with certain emotions, for example red can be associated with love, passion, warmth or even anger.'* IDS18

> *'Most people would associate the colour red with anger but also in contrast with love. Blues and light green with feeling calm. Yellow with feeling happy. Generally dark colours with bad moods and bright fresh colours with happy moods.'* IDS16

> *'Yes. Red can be associated with anger, but stimulates thought. It certainly doesn't feel like a restful colour.'* IDS3

The quotes above show signs of colour associations with particular emotions. Even though these students might not entirely agree with these generalisations, their views have been to some degree biased by such links. Furthermore, another explanation is that because most people share these beliefs the students do not feel confident yet to challenge them.

'Yes I believe that orange makes people feel warm. White makes people feel peace and clean.' IDS5

'Yes. Yellow colours give warmth. Blue colours give cool.' IDS17

'Yes. For example dark colours put a person in a moodier state of mind and brighter, fresh colours generally put people in a happier state of mind.' IDS21

These three examples show approaches that are related to the attributes of colour such as the temperature and the degree of brightness. So the general idea here is that warm and cool colours can evoke contrasted feelings and emotions, and that brighter schemes create more pleasant interiors than darker ones.

b. Colour perception approach

'I do believe that certain colours are associated with certain emotions but they all depend on the person's cultural upbringing. E.g. red could be associated with love, danger; white with purity; green could be envy or have a calming effect, heighten the concentration of the person.' IDS15

This student recognises that the colour associations are influenced by *culture*. She provides some examples of contrasting emotions which can be evoked by the same colour to argue that there is no fixed way of connecting a colour to an emotion. Note that this is an international student thus, after spending time in the UK she has probably experienced the variations in cultural beliefs relating to colour.

'I do believe that certain colours evoke emotions but that are specific to individuals. For example, blue is a colour that I like and for me would most likely evoke happiness whereas it can often be associated with sadness. However in an interior I feel that other factors apply to the emotion evoked such as lighting etc.' IDS12

This student acknowledges that colour associations depend on *personal colour preferences* and the individual's previous experience. So, despite existing stereotypes, people's own experiences play an important role when correlating a colour to an emotion. She provides an example of such personal preferences (that she likes the colour blue), yet she accepts that her view might not be shared by others.

'In some situations, certain colours are associated with certain emotions. People have different feelings towards one colour. In hospital always choose white. However, the environment can change, [under different conditions] such as strong light or reflections can create a different feeling of one colour, e.g. white is peaceful… but white under strong light is not comfortable anymore.' IDS20

The above participant also raises the issue of personal preferences. However, she also argues that *colour appearance can change* under different lighting conditions for example; hence when the same colour is viewed under different light it may evoke different emotions. Therefore, as the appearance of colour can change, there are no fixed links between colours and emotions.

c. Design approach

'Yes, there are obvious stereotypes but I wanted my space to feel intimate, wild, soft and bright as well as dark. I could have chosen reds, yellows… but I feel that purples have such a wide range of emotions to offer.' IDS6

This student's design approach was not so influenced by stereotypes. She used colours that she likes, without offering a more sophisticated rationale for her decision, yet she believed that everyone would probably share her views.

'I have chosen natural colours. I think that colour should be comfortable for people. We are watching for a long time. This brown is ground. This colour is skin [arrow pointing at the pastel orange]. This white is cloud.' IDS11

Here we see a different approach to colour use which associates colour not to emotions but to elements. So, in this example, the brown signifies the ground, the pastel orange the human skin and the white the clouds. This student treated the interior as a painting composition for which she used the colour symbolically.

Question 2: *What sort of feeling do you expect your interior will produce?*

Although some students provided a rationale for their colour choices during the first session of the activity, this question expected to record what sort of feeling they intended to generate. Later on, during the group discussion, the *intended feeling* (the mood that each learner had intended to evoke) was contrasted to the *evoked feeling* (what the learners actually felt while inside the interior). This also gave me an indication of how confident students were in predicting the impact of their colour choices. In most cases, as the ones presented below, the participants opted for a safe answer by providing a mixture of feelings or opposite emotions, which also implied their awareness that different people might feel differently in the same space:

'I hope for a mixture of feelings! Comforting, wild, nostalgic, intimate, gloomy with aspects of hope. Directional, but also getting lost (contradictory).' IDS6

'I feel that my interior will produce cosy, dark, warm, passionate and maybe even devilish feelings…' IDS18

'I expect my interior would make a person feel safe but maybe still feel that the interior is quite impersonal. ' IDS12

'This room gives a combination of warm and cool and gives the feeling of wide and narrow.' IDS17

'Comfortable, relaxed when people come into the space first a little surprised, even shocked from the first view and then begin to enjoy it and experience it / discovering and finding new things.' IDS20

Some students gave more ambiguous descriptions of the feelings that their interior might evoke:

'I expect a feeling of femininity and youthfulness will be produced from this interior. It's a fun space, very bright.' IDS16

'The colours chosen for this interior are very masculine and boyish.' IDS21

6.2.2.2 The VR session

At this stage the students were led to the VR room. They were given the 3D goggles and were instructed to stand as central as possible to the screen so as to have a better view and sharper stereoscopic effect. They were told to avoid turning their heads too much as the eye-tracker positioned at the top of the screen might lose contact with the receiver on their goggles and create a flickering effect. They were also handed the page with the emotion scale on an A4 cardboard sheet.

As mentioned previously, initially each student navigated inside a neutral coloured room so as to try out the joystick and familiarise themselves with the goggles and 3D depth perception. The average time spent inside a room was seven minutes, while the overall time spent inside the VR room did not exceed the 35 minutes. Some participants had to explore two rooms to cover for students who did not attend.

During the VR session only a few comments were voiced about the colours of the rooms. Usually, when the doors of the virtual rooms opened, there was an element of curiosity and surprise. All participants commented on how the same room appeared so different when other colours were used. A few of the rooms caused a commotion due to their extreme look and others seemed to be uncomfortable to look at for a long time. Students were asked to write down those impressions even if they were not immediately related to emotions.

Through the entire exercise, the learners were asked to work alone and not to show their design to their peers. The 3D rooms were kept anonymous as it was believed that the students would feel more open and confident to comment on a room if they did not know who had designed it. Nonetheless, due to the small size of the groups, the participants were able to guess the designer of each room through a process of elimination and probably familiarity with their peers' style of design. It was noticed, that in the two groups that had two non-attendees, the participants felt less reluctant to comment on the negative aspects of the rooms designed by those students.

As expected, some learners were better at navigating inside the rooms than others. Previous gaming experience does not guarantee better navigation skills as the controls and size of the screen are different to most commercial video games. A slower pace is recommended as it allows viewers (the ones who are not controlling the movement) to adapt their eye gaze and follow the route without experiencing sudden movements. In general, there are always a few people who would treat the VE as a game and try to explore it as fast as possible causing discomfort to the rest of the viewers. Therefore, it came as no surprise that towards the end of the VR session two participants felt slightly dizzy due to motion sickness.

6.2.2.3 Responses to the second questionnaire

Subsequent to the VR session, the participants went back to the meeting room. I collected the first questionnaire and the emotion scale sheets and handed them the follow-up questionnaire. Here I provide some of the student's responses:

Question 1: *How important is colour in your work?*

The idea was to encourage students to reflect on their own practice and experience and give an insight into how they use colour in their projects. For all of them colour is very important as it defines a space, alters the perceived size of an interior, enhances its features, creates an ambience and mood, adds purpose and function, etc.

> *'Colour is very important – it makes all the difference - it makes a room look smaller or larger or even longer. It gives a definition to the space we live in.'* IDS18

> *'Incredibly so. Colour enables you to design in a way that pulls different demands together. It can be used to direct its occupants, evoke a feeling or mood and create a desired ambience.'* IDS3

> *'Extremely important. In an interior space colour can completely change the mood, the aesthetic and the emotion the space evokes.'* IDS16

> *'Colour plays a very vital role in any piece of work. As we have just experienced, the colours of an interior set the mood and mind set whilst in the space. Cleverly selected colours can emphasise certain features of a design.'* IDS21

One student commented that the wrong use of colour can have a negative impact on the overall design, while the right use could further improve a design:

'Very important. I think colour is a key element… it can influence the mood of an interior and the mood of people. If you use the right colour it will strengthen the mood of your work. If you use the wrong colour it could destroy the advantages of your design.' IDS5

The following student touched upon one of the issues discussed in section 3.1 of this chapter: that the current interior design curriculum gives more emphasis on form and less on colour.

'I think it's the first thing I think about, after how I want my interior to feel, but it always gets discarded in favour of forms, so this project was great!' IDS6

Question 2: *Do you normally use colour for aesthetic or practical reasons?*

This question aimed to make students think of how colour can be utilised both for practical reasons as well as aesthetic. Interior designers should be aware, especially when designing a public building, that colour can also be used to guide people such by highlighting the exits, the corridors, the stairs, etc. Colour coding, for instance, is often utilised to quickly communicate information to the public (e.g. where the reception or the information desk is, the telephone booths, etc). Note that these students are in their 2nd year of their studies hitherto their project assignments have not considered public spaces yet. However they should be aware that colour does not only serve aesthetic purposes but that it is also a way to convey information. Nevertheless, most of the learners appear to have a rather simple understanding of colour use in interior design:

'Definitely aesthetic.' IDS6

'I consider both usually but more often I use colour aesthetically.' IDS21

'I prefer to use colour for aesthetic reasons, however the balance between aesthetic and practical would be the best solution.' IDS15

'Normally for aesthetic reasons. Although in certain spaces the practicality of a colour in a chosen area must be considered.' IDS16

For other students the use of colour depends on the type of interior (public or residential) and the function of the space. For residencies the majority would utilise colour aesthetically. Interestingly though, if the target occupants are not known (i.e. potential buyers of a house or a flat) the designers would opt for a neutral colour that would not evoke any strong reactions or emotions. This issue again relates to how colour can be subjective and that people's views may vary, therefore a neutral colour such as magnolia should be inoffensive and please the vast majority of the population.

'That would depend on the function of the interior of a public building; colour may be used to alert or draw attention to. In a residential setting, colour would usually be used to create a desired ambience and therefore be chosen for aesthetic reasons.' IDS3

'The use normally depends upon the room we have to colour. Like if we have to paint a house for sale we will always paint it magnolia as it's universally approved. And if we want to paint something personal we will use colour for aesthetic reasons.' IDS18

The participant below expressed that he does not feel confident when applying colour to a design

'…Actually, I am not very good at it. But I always choose a main colour and then choose another one that has some relationship with the main colour.' IDS5

Question 3: *When you are choosing a colour scheme for an interior what are your main considerations?*

This question originally intended to generate a dialogue regarding the factors that can influence the appearance and perception of colour. Most students believed that the function of the interior was most important, while other factors were also mentioned:

'The occupants, its use, the brief.' IDS3

'The purpose of the space and who will be using it are the main considerations when choosing a colour scheme. There are many different colour schemes that would be aesthetically pleasing but not necessarily in the situation you place it in.' IDS16

'What is the purpose of the interior? That would greatly affect my colour choice.' IDS8

'The feeling I want to achieve and whether the colours communicate well with the function of the room, whether they are aesthetically pleasing or not.' IDS15

Other participants' are more concerned about the look and feeling of the design:

'When we choose a colour scheme for an interior we always consider how we want the room to look for example if we want a fresh look we will go for white and baby blue, if we want modern we will go for more colours and play with a neutral (white) and bright (red) colour.' IDS18

'The feeling the colours will create and if they match any particular features of the interior, emphasising certain emotions.' IDS21

'The atmosphere that I want to create in conjunction with the lighting, space, materials that I have available.' IDS12

Question 4: *Was the visual impact of the chosen colours different when viewed on paper, on the laptop screen and on the VR display?*

This question prompted students to think of the three media (paper, laptop screen and VR) and discuss whether and why the same colours appeared different. This was a way to introduce a question with regards to the technology without diverting the participants' attention from the topic of colour.

All the participants agreed that the visual impact of the colours was different. The larger scale of the virtual rooms allowed them to study the relationships between the colours more thoroughly (i.e. when two colours meet at a corner, or how a different colour door may stand out from the wall).

> *'Indeed it was. I perhaps tried to think too much about the colours relating or not to each other on paper and not the feeling one might experience when in the room. Once inside the 3D VR environment, the experience is completely different. In life sized scale the experience of seeing how the different colours relate to one another and how your mind reacts to those environments is fascinating.'* IDS3

> *'Yes it was more dramatic in Virtual Reality. I thought that it would be dramatic but just in a way that made someone interested rather than intimidated. I did achieve the sense of surprise I wanted at the entrance though.' IDS12*

Some students commented that the colours appeared darker or brighter in the VE (they should look slightly brighter due to the rear-projection display). These variations in appearance are also attributed to the size of the area the colour covers (e.g. small colour sample, laptop screen and nearly life-size scale on the VR display). Most people have encountered this problem when painting their walls in their homes; after painting a whole wall they realise that the colour looks darker or lighter than on the sample. Interior design students should be aware of this phenomenon: that colour appearance changes with scale. This learning activity demonstrated this issue, and challenged some students to reconsider their design.

> *'Yes, a little. My room felt darker in the Virtual Reality environment. I wish I had made it a little less dark. The space felt a little smaller from what we had seen on paper or laptop.'* IDS18

> *'Yes, on paper it looked a lot darker and on the laptop. The VR was good and I liked the way it looked, but I would have made the ceiling black because it looked too bright and made some things stand out more than I wanted to.'* IDS6

Participants said that they had imagined their room differently, in terms of look, feel and scale. Some thought that it did not look as good on the VR display as opposed to the laptop screen. On the other hand, one student expected her room not to be so pleasant since she used colours that she would not have normally chosen, yet, when she saw it on the immersive display, she was realised that this colour scheme had worked quite well.

'Yes. Sometimes my imagination is different from the one appeared on paper, because of the size and the scale and so on.' IDS20

'Some of the colours did work well together in some areas and they did not work as well with the others. In the VR environment the impact was different to the impact I had achieved on laptop.' IDS15

'On paper they weren't colours I would normally choose to go together. They seemed very bold, however on the VR environment they seemed to work quite well to give a happy environment.' IDS16

Apart from studying how the colour schemes worked in each room, the students also noticed that the VR experience gave them a better understanding of the space as a whole. This issue will be further analysed in the next section.

'Yes, the virtual reality environment gave a much clearer understanding of the space. This is something the laptop can only do to a certain extent and paper not at all.' IDS21

6.2.2.4 The group discussion

The group discussion originally intended to provide an opportunity for the students to comment on the colour schemes and share their views about the VR colour experience. The main goal was to raise awareness that the same room could evoke different feelings in each person and that it is not easy to predict colour appearance and perception within an interior space. A chart, which contrasted the *intended feeling* to the *evoked feeling*, along with the results of the emotion scale for each room was presented to them.

Even though this exercise was not assessable, it was anticipated that some students might be hesitant to express their opinion about another peer's room and might prefer to keep quiet so as not to receive bad criticism either. Therefore the designer of each room was kept anonymous. It could be argued that only the scales resulted in honest and unbiased comments about the feeling of the rooms. The purpose was not to reveal which design generated the most positive or negative feelings but to show that people's opinions vary. The charts instigated a conversation regarding the subjectivity of colour and how interior designers should be prepared to deal with this issue.

When a room evoked mostly positive feelings the emotion scales would incline towards the left (1, 2 or 3) and when a room generated negative feelings the scale would lean to the right (5, 4 or 3). For some designs there was agreement between the participants while for others the ratings spread from 1 to 5 denoting that these rooms had caused mixed reactions. Table 5.3 shows the intended and evoked feeling for two rooms (IDS18 and IDS5) while Table 5.4 and 5.5 depict the ratings for these two rooms.

It is worth mentioning that students' opinions about the rooms might have been influenced by other factors not related to colour. The stereoscopic vision, the big scale projection and the navigation for instance, could potentially have a subliminal effect on the students' judgement. Moreover, strong order effects may as well affect, to some extent, people's opinions. In this study in particular these effects had at least two origins. The first one had to do with the number of rooms and the fact that the more designs someone sees the more able he/she is to judge and articulate comments based on comparison. The second had to do with novelty; the first room probably would have been judged differently since the novelty effect is very strong.

The learners were curious to find out how their design was seen by others. Occasionally, even the designer of a room would change his/her opinion about its effect. This also demonstrated that predicting how a colour might look on a big wall rather than on the small colour chip is not easy and it requires experimentation and a number of trial and error processes.

The questions of the second questionnaire were also discussed. The students expressed a concern with regards to how to present a design to a client (someone who is not an expert in reading architectural drawings). Furthermore, they discussed how they could make a client realise that his/her design idea might not be suitable for the interior without offending them. The students considered the immersive VE as a solution for the above issues as they could present their designs in a form that is comprehensible by most people. Others appeared less keen to show a detailed finished outcome to clients, even so they agreed that they would like to use the VR display as a tool during the design process to view and study their interiors and identify potential problems.

All the learners concurred that the VE gave them a better understanding of the space. Given that they had not designed the layout themselves they probably could not estimate accurately its size and the dimensions of the features inside it from the floorplan on paper or the 3D model on the laptop. This matter will be analysed further in section 6.3.

Towards the end of the session the students were shown prints of all 20 room designs. They were surprised to see the variety of the colour schemes particularly since they had only 21 colours to choose from and use only 5 (with additional restrictions). This sparked a dialogue about how some rooms reflected the designer's individual style, why purple had been chosen by many students while only one had selected green and that they would be interested to see all 20 on the VR display.

In general, the group discussion was successful in terms of getting learners to express their views about colour use in interior design. The average time for this session was 30 minutes; obviously for the groups that had less participants the duration was shorter.

Table 5.3: The table contrasts the intended and the evoked feeling for two students' rooms.

Room	Intended feeling	Evoked feeling
Room IDS18	Cosy Warm Passionate	Moody Cool Fun Powerful Mysterious Confusing
Room IDS5	Warm Simple Peaceful	Industrial Interesting Warm Bright Complex

Table 5.4: Shows four students' ratings for room IDS18

Comfortable	1	2	3	4	**5**	Alert
Relaxed / calm	1	2	**3**	4	5	Insecure / Disorientated
Surprised / Excited	**1**	2	3	4	5	Annoyed / Anxious
Happy	1	2	**3**	4	5	Depressed / Melancholic

Comfortable	1	**2**	3	4	5	Alert
Relaxed / calm	1	2	**3**	4	5	Insecure / Disorientated
Surprised / Excited	1	**2**	3	4	5	Annoyed / Anxious
Happy	1	**2**	3	4	5	Depressed / Melancholic

Comfortable	1	2	3	4	**5**	Alert
Relaxed / calm	1	2	**3**	4	5	Insecure / Disorientated
Surprised / Excited	**1**	2	3	4	5	Annoyed / Anxious
Happy	1	2	**3**	4	5	Depressed / Melancholic

Comfortable	1	**2**	3	4	5	Alert
Relaxed / calm	1	2	3	**4**	5	Insecure / Disorientated
Surprised / Excited	1	2	3	**4**	5	Annoyed / Anxious
Happy	1	2	**3**	4	5	Depressed / Melancholic

Table 5.5: Shows four students' ratings for room IDS5

Comfortable	1	2	3	4	**5**	Alert
Relaxed / calm	1	2	**3**	4	5	Insecure / Disorientated
Surprised / Excited	1	**2**	3	4	5	Annoyed / Anxious
Happy	1	2	**3**	4	5	Depressed / Melancholic

Comfortable	1	2	**3**	4	5	Alert
Relaxed / calm	1	2	3	**4**	5	Insecure / Disorientated
Surprised / Excited	1	**2**	3	4	5	Annoyed / Anxious
Happy	1	2	**3**	4	5	Depressed / Melancholic

Comfortable	1	**2**	3	4	5	Alert
Relaxed / calm	1	2	**3**	4	5	Insecure / Disorientated
Surprised / Excited	1	2	3	**4**	5	Annoyed / Anxious
Happy	1	2	3	**4**	5	Depressed / Melancholic

Comfortable	1	2	3	**4**	5	Alert
Relaxed / calm	1	2	3	**4**	5	Insecure / Disorientated
Surprised / Excited	1	**2**	3	4	5	Annoyed / Anxious
Happy	1	**2**	3	4	5	Depressed / Melancholic

6.3 Post-Interviews

The post-interviews were scheduled two months after the trial[34]. The students who participated in both first and second sessions of the exercise were interviewed individually. The intention was to find out their views with regards to the colour learning activity and the implementation of the 3D technology. The learners' views are offered below.

7. The Post-Interviews

The students' responses were analysed and categorised under two main themes: the *colour learning activity* and the use of *VR in interior design education*.

7.1 The Colour Learning Activity

The students' responses presented in this section refer to the strong and weak points of the particular colour learning activity. The student below commented that the visual impact of the colours was completely different on the VR display, on the computer and on paper. The technology allowed them to explore the interiors in a natural manner, similar to walking inside a real room and observing it from various angles. So, the objective to demonstrate to learners that the appearance and perception of colour can be influenced by the size of the coloured area and by the medium used had been achieved.

> *'It was really interesting to see the colours you had chosen and then see them in a completely different way. Obviously choosing the colours from a piece of paper and applying them on the computer was completely different to what it looked when you were actually in the space. It was also fun to walk through the space and try to navigate your way through and see the different angles and the different moods that you get from the colours.'* IDS16

Another issue that this learning activity attempted to raise was the one of personal colour preferences and beliefs. Student IDS15, although she seemed conscious that people's colour preferences are influenced by culture, age, previous experience, etc., when she was shown the images of all 20 interiors, she was surprised and intrigued by the variety of colour schemes and the colours her peers had chosen. Hence this activity was something like an eye-opener for this student.

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[34] Initially, I intended to conduct the interviews one month after the trial, but that coincided with the Easter break, hence another date that was suitable for the department was arranged. The rationale for allowing some time between the trial and the interview was to see if the activity was a memorable experience for the students. In addition, since the effect of the 'wow' factor should have faded after that time the students were expected to reflect more on the aspects of the technology that could enhance their learning.

'Probably when we went back [to the meeting room] *to discuss how people chose the colours and how many people had chosen a particular colour […] because they were only two people that had chosen green, that was quite interesting. Yes I found that aspect really interesting -to see how people choose colour.'* IDS15

The participant below had a similar, yet more extreme, reaction to the colour choices of her fellow students. I present here some quotes from our interview dialogue in order to show that she initially had a narrow-minded approach towards colour preferences and expected everyone to agree with her ideas and yet towards the end of the activity she was more willing to negotiate her ideas and accept that people's preferences and reactions to colour may differ.

'One interesting thing [about the learning activity] *was to see how awful the colours were. The computer, with so much light added, made the colours a bit vile. And then you think "Why would someone pick that colour? It's hideous!" That was interesting.'* IDS8

'…when you have picked certain colours because in your mind you have an idea of what you think they represent, such as calm and peaceful, and then someone says "Well I actually think it's quite frightening", then you almost feel that you have to defend that "No, that's not what I think" and I kind of felt that everybody had done that at the end.' IDS8

When she was asked which was her least enjoyable part of the learning activity she replied:

' When people say bad things about your colour choices' IDS8

When she reflected on her learning experience, she acknowledged that through experiencing such situations, in which she felt an urge to defend her design decision, she actually learned new things, and most importantly she learned how to reconsider her ideas and process the knowledge that she gained.

'Yes, but was fun to do new things, and learning new things sometimes shutters your preconceptions of the thought that everybody has the same idea of something.' IDS8

This quote gave an indication that the activity had somewhat challenged the learners' pre-conceptions and naïve beliefs, which is an important starting point for the acquisition of new knowledge.

A learner mentioned (section 6.2.2.3) that colour is being discarded in favour of forms and that most of the project assignments do not give adequate emphasis to colour use. The same problem was raised by the student below.

'I have studied psychology before so I'm really interested in colour and the feelings [it can generate] *in interior spaces. So I was really interested in this project. I want to learn more* [about colour and emotion] *but we don't have many projects on colour.'* IDS11

This also confirms the initial finding with regards to the lack of colour education, discussed in section 3.1. As a result of this, the learners were slightly confused at the beginning of the activity as they had not previously been assigned a similar project. Although I explained to them all the stages of the task, they did not, at first, really understand the purpose of the activity.

> *'When you came in first and we had to choose the colour, everyone was "what is this kind of thing?" But then once we got into the VR studio it all made sense. I think maybe you had to explain a bit more at the start what was going to happen.'* IDS15

One logical explanation for this miscommunication is that they did not know what a VR environment was as most of them had not seen one before. Explaining how a VR display looks like is not an easy task as one has to experience it first-hand in order to appreciate it. However, this also shows that the purpose of the activity had not, perhaps, been communicated effectively to the participants. Usually learners prefer to know the content of their courses and their lectures so as to have better control over their learning. Kinzie et al. (1992) indicate that when students feel in control of a learning activity, it develops meaning for them, and increases their motivation for the task. Furthermore, the fact that the researcher was not familiar to them probably also contributed to the confusion since the students may not have been comfortable to ask for further clarification at the beginning of the trial.

7.2 VR in Interior Design Education

The interview also involved questions concerning the advantages and disadvantages of the VR display. All of the participants reported that they enjoyed the experience and that it was something they had not seen or done before. Only two participants felt a slight dizziness caused by motion sickness which is a usual phenomenon reported in most VR studies. Some students encountered problems with the joystick control and could not navigate smoothly inside the rooms. So, despite these issues, which are mainly generated by unfamiliarity with the technology and could probably be resolved after more exposures to the controls and the VR display, it was a pleasant and memorable experience. The following quotes suggest that it was not only the effect of depth perception that made this activity enjoyable but the fact that they could navigate *inside* the rooms. Being able to explore the rooms from the inside also gave them a better understanding of the space.

> *'Probably the fact that you could actually navigate through the model instead of you looking at it from outside. Because you could actually turn around corners and you were almost looking around* [turning your head] *even before reaching the corner.'* IDS16

'I suppose it was the fact that you were able to go inside it. You can walk around your model in VectorWorks [the software the department is using] *but actually being inside it I think was the most effective bit.'* IDS21

'I think the best part was actually to getting to travel around the spaces that you had seen on paper. It helps you understand them a lot better.' IDS21

The interviewees were asked if they would be keen to use the technology again and how they thought they could benefit from it. All of them replied that they would be interested to use the technology again, if given the opportunity, in order to explore their own designs. They felt that current visualisation techniques (architectural drawings and 3D computer models) did not offer them adequate feedback about the scale and feeling of their interiors, mainly because of the size of the visuals and the restricted viewpoint. Their responses confirmed the educational problem discussed in section 3.2, that students never get to create and experience their designs in full scale. From their point of view an immersive display could resolve this issue by eliminating these practical and physical limitations, which also verify the hypothesis of this study.

'Yes I would be keen to use the technology especially to see my designs in 3D. Because the designs that we do in here are just exercises and you don't see them in real life, which is a shame. Of course that cannot happen for every single project that we do, but it would be nice to see how it would look like in real life […] so maybe just use it [immersive VE] *for that.'* IDS15

'It would be good to be able to put our own designs on [the VR display] *because it could definitely give you a feeling of the space. We obviously do it on the computers and you can, to an extent, see different angles and choose your views and things, but there is still a part of you who would love to be able to actually create the design so you could be inside it to see also how things are related to each other. So I think it definitely helps'* IDS16

'…because when you are designing it [the interior], *sometimes from plans and sections you think it's going to work and then when you are in it, it might not have the same kind of atmosphere'* IDS12

'I think it could be really helpful if we could put our own design in it. That would help us a lot more. Maybe on paper it looks good but once you are actually in the space it's completely wrong.' IDS21

Some ideas about how a similar system could be integrated in the design process were discussed. One student suggested that the technology could be utilised to demonstrate more effectively some design details:

'Yes definitely, because when we design an interior you only see it in 2D on a computer screen which is quite small so you might not see some of the details and sometimes it is hard to show the

details on the computer drawings unless you really, really zoom in and then everyone goes "what is that?" because they miss the bigger picture. Whereas in a VE it could be easier.' IDS15

The student below suggested that it would be beneficial to view the (empty) interior space through an immersive display at the start of each project and then proceed to the design process (often professional interior designers have the opportunity to study the space before designing it):

'… when we came back here [at the interior design studio] *and we were working on our other projects, we were just thinking how good it would be to do something like that just before starting a project, to see how the space looks like.'* IDS21

Other participants considered that the system could enable them to review their design and identify potential problems which they cannot detect as easily from the drawings or the 3D computer model. When this student was told that they will have the opportunity to explore their own designs in a VE in the future (Study 3) she replied:

'*That would be nice! And then we will realise that our designs are actually dangerous*!' IDS12

8. Discussion

8.1 About the Findings

This section discusses the main findings of the *Colour Experience* study. The open-ended evaluation approach apart from being more suitable to the project-based educational philosophy of the discipline, also allowed for the detection of unexpected findings. The findings are presented in turn below.

The educational objective of bringing home to students the variation in subjective colour experience was achieved with many of these students. By observing the participants during the group discussion and through the post-interviews it became evident that they experienced surprise, with regards to the colour schemes' variation and to other learners' colour preferences, and began to re-evaluate how they should respond to this (by being defensive?, by accepting the range of different judgements? by changing their design to satisfy the majority?). This gave a strong indication that the activity had challenged the learners' pre-conceptions and beliefs, which according to the theory of constructivism is crucial for the acquisition of new knowledge.

It also became evident that the ability to explore an interior space from the inside allowed students to study the effects of colour more effectively. The objective to demonstrate to learners that the appearance and perception of colour can be influenced by the size of the coloured surface has been achieved. The larger scale of the virtual rooms allowed them to study the relationships between the colours more thoroughly and experience the feelings and moods that the colours evoked. The students also mentioned that the VR technology gave them a better understanding of the space as a whole. This is in alignment with the hypothesis that an immersive system could enhance current learning and teaching methods in interior design by offering students the opportunity to become immersed inside a real size 3D model, which so far has not been possible for reasons relating to cost, space, time, etc. Hence, as this study demonstrated, the use of this technology could offer a solution to this education problem.

One of the main educational methods that had been incorporated in this activity was the generation of a *dialogue* between peers. It seems that the learning activity and the technology encouraged interaction between the members of the groups as well as between the learners and the researcher. The VR system allowed for a shared experience (multiple learners viewing / experiencing / reviewing / critiquing the same design), which is in line with the teaching philosophy and the foundation of crits in Art and Design education. In particular, for topics as the one examined in this study, the range of reactions is even more important than the content of any one reaction. The problems for interior design that refrain students from *seeing and experiencing* their own work also limit the exposure of the work to their peers, therefore an immersive VE could potentially help in this respect too.

From observations of the students navigating inside the VR rooms and from comments raised afterwards it became apparent that for a significant subset of students the 2D floor plan and the 3D model had failed to communicate the actual size of the interior. A significant subset of students had not realised important aspects of the spatial layout from the plans until they experienced them in the VE. Visualising spaces on the basis of 2D plans and elevations is a skill that develops through experience. Some students cannot yet accurately estimate the scale and feeling of a space only from reading 2D drawings and seeing the 3D computer models. That is the reason why most of them were keen to use the technology to review their design decisions, identify problems and test if the design works as they had imagined or whether it requires further refinement. The participants considered the ability to walk inside the 3D models pivotal for enhancing their spatial awareness.

8.2 About the Study

This section begins with the questions that troubled me since the beginning of this study: How can I measure learning especially when dealing with a topic as subjective as colour? How can I ensure that the learning activity was effective?

In some cases learning cannot be measured with numbers and statistics like it happened in Study 1. The first study of this research involved colour theory concepts, which if an appropriate testing session is carried out after the activity it probably could assess if the participants understood the concepts or not. The learning task, as designed in Study 2, did not aim to teach students how to create harmonious colour schemes or which colours they should use for particular interiors (e.g. residencies, bars, stores, hospitals, etc.). The learning objective was to challenge the students' views about colour and encourage them to accept other people's beliefs and maybe re-evaluate theirs. Hence this learning activity was designed with the view to cultivate their knowledge and attitudes towards colour and to prepare them for what might come after their studies when they will need to communicate with clients and colleagues.

Therefore, in order to evaluate the effectiveness of this learning activity I devised ways to capture the learners' comments, feedback and suggestions in a manner that was not obtrusive to the learning process and flow of the task. The questionnaires were designed to be part of the learning task, providing at the same time valuable data regarding the students' pre- and post-approaches to colour use. The post-interviews proved very beneficial as it was crucial to capture the students' opinions about their learning experience. This is in line with the philosophy that learners should be involved in the design of the educational curricula which evidently allows them to have better control over their learning.

To evaluate whether this learning activity had an impact on the students' subsequent choices of colour schemes for their designs would require more exposures to similar activities. Furthermore it would require a long-term study and probably more frequent contact with the students as the researcher should become more familiar with the students' work so as to observe their progress over a lengthier period of time. Additionally, a comparison between a group of students that uses the technology to a control group (e.g. 3rd year students) would probably provide further information about the impact of this VR-based learning activity. Still, in order to draw this comparison would require again a higher level of familiarity with the students and their work. But, as I am not a tutor at the interior design department and thus I have no regular contact with the students, it was not feasible for me to infer the effects of this learning activity on how the students used colour in subsequent projects.

Possibly another way to evaluate the students' understanding of colour use after the learning activity (probably a month or so later) would be to employ a method based on work in the area of critical thinking. For instance, a simplistic approach is one that describes a design in terms of simple colour names (e.g. 'I'll paint the walls yellow'), while a developed appreciation includes fewer simple descriptions, recognition of parameters that may influence perception, discussion of reasons for a choice, and choices that themselves involve subtlety such as shades that remind viewers of more than one colour and that seem to vary over the expanse of a surface. In other words, examine whether the students colour sensitivity and vocabulary has been enriched by assessing if they are able to offer a more elaborate explanation with regards to their choice of colour.

8.3 Issues and Limitations

Two participants, during the interview, mentioned that initially they did not have a clear idea of the purpose of this learning activity. Only towards the final stages of the learning activity they understood the purpose of the exercise. This issue could be mainly attributed to lack of communication between the researcher and the students. I explained previously that since I am not a member of staff at the interior design department the students were not familiar with me and probably they did not feel comfortable to ask questions in the beginning in order to clarify the purpose of the exercise. Furthermore, if I were to repeat the study I would revise the introduction to the task and I would make sure that the students have understood the activity and their role in the study before proceeding to the next stage. In the following study however, I attempted to involve the students' tutors in the study, in order to perhaps resolve the issue discussed here.

Another explanation for this issue is that the interior design department at GSA is not offering a dedicated course to colour hence this task was not something that the students had done before. Although this activity could be carried out as a one-off exercise during the second year for example, it would be more effective if it was accompanied by a theoretical course on the use of Colour in architecture and interior design. This course should be more focussed on perception and phenomenology than colour theory. The learning activity presented here would fall into place if it could be supported and interpreted by theory offered in form of short lectures. Again, as in Study 1, a balance between theory and practice could offer better learning outcomes.

The quality of the graphics could be seen as a limitation of this study since the 3D models had no shadows, reflections, refractions, textures, etc. Nevertheless, the objectives of the learning activity were met even with non photorealistic quality. This issue can be resolved by using more advanced VR application software and display. Many computer science studies are working on ways to create photorealistic VR environments For instance, at Chalmers, the school of Architecture and the department of computer engineering compared light simulation between a physical room and a VR 3D-cube room (Billger & d' Elia, 2002). The study focused on the simulation of light and colour appearance in VR. The main goal for this project was to make VR a usable design tool for the planning of light and colour in buildings. By comparing assessments of the perceived light and colour in real rooms to simulations in immersive Virtual Reality (3D-cube), they attempted to solve problems in the design process related to the difficulty to visualize and comprehend the way light and colour will appear. Interior design and architecture could benefit from the outcomes of such studies since these VR environments could be used for educational purposes.

Another limitation of this study is that it tested only one display, a semi-immersive VR display. This issue was taken into account in the follow-up study presented in Chapter 6 which gave the opportunity to repeat a similar learning activity, and compare and evaluate the effectiveness of two different spatially immersive displays.

9. Conclusions

In a nutshell, this study provided favourable results with regards to the effectiveness of the learning activity and the use of the VR display for learning and teaching the topic of colour experience to interior design students in particular. The open-ended measures (questionnaires, observations, group discussions and post-interviews) showed that the educational objectives of this learning activity have been met. Given that the intention of this learning task was not to teach facts or skills but to cultivate students' understanding, quantitative measures would not have been a natural measure to apply while the qualitative techniques applied here were naturally integrated in the learning activity without being obtrusive. Moreover, this type of assessment is familiar to Art and Design students.

In brief, the educational objectives that this study had set were met with many of the students. The immersive VE made them realise that when the same colour is applied on a large wall and on a small colour sample will not have the same effect. In addition, the fact that the colours were experienced in context in the rooms as opposed to being small squares on a colour palette also had an effect on the perception.

It was noticed that the learning activity promoted peer interaction, which as discussed in Chapter 2 is crucial for Art and Design education. Moreover, it also became evident that the existing visualisation methods may not be adequate to communicate the actual scale of an interior, especially to novice designers. These two findings formed the rationale to conduct a follow-up study, namely *Spatial Understanding*, with the same group of students, yet this time focusing on scale and spatial relationships rather than colour. Furthermore, although nowadays this type of VR equipment is far more affordable than it was a decade ago, its cost can still be quite substantial for an Art and Design institution. Therefore, the subsequent study examines the impact of the same VE using two different immersive displays: the semi-immersive VR display (stereoscopic) as used in this study and a widescreen wall projection (non stereoscopic); the latter is a cheaper spatially immersive display. This comparative study is presented in Chapter 6.

Chapter 6

Study 3: Spatial Understanding

How this study fits in the thesis

The findings of Study 2 showed that interior design students' spatial design ability might not be as developed at the early stages of their studies. This study aims to investigate whether an immersive VE could accelerate the acquisition of that skill by enhancing student's spatial understanding of the interior design projects. This chapter begins by presenting an educational problem and continues by proposing a solution that involves a learning activity that uses 3D visualisation technology. In a nutshell, Study 3 attempts to demonstrate a third example of how this type of technology could supplement and enhance current learning and teaching methods in Art and Design education.

1. The Topic: Spatial Understanding

1.1 The Rationale behind the Selection of the Topic

The idea for this learning activity emerged from remarks that some students made on the scale of the 3D room used in the *Colour Experience* study presented in Chapter 5. Before the VR trials, the students had seen the 2D drawings of the room and a 3D model of it on a computer screen. However, after exploring the room in the Virtual Environment (VE) using a semi-immersive VR display, some commented that they had imagined the space to be of a different size, i.e. smaller / bigger, which meant that their mental image of the room did not correspond to its actual dimensions. This was not an unexpected finding. The ability to create an accurate mental image of a three-dimensional space (imagined or existing) usually develops through experience and practice. Many second year students are still at the early stages of this learning process, thus the majority of the projects aim to help them acquire this skill.

Moreover, the post-experience interviews with the participants provided better insight into which aspects of the technology the students considered to be more important for studying a 3D model and thus for enhancing their spatial awareness. In particular, the learners valued the ability to 'walk' inside the 3D model through first-person navigation for comprehending the 3D interiors.

Therefore, by reflecting on the students' comments on their first experience of using a spatially immersive VE to explore their interior designs this follow-up study was conducted. This involved the design and evaluation of a learning activity that focused mostly on form, volume and spatial relationships. Hence the main aim of the *Spatial Understanding* project was to allow students to experience the spatiality of their designs through the use of an immersive VE.

1.2 Spatial Ability, Spatial Skills and Spatial Visualisation

The terms *spatial ability*, *spatial visualisation*, *spatial awareness* and *spatial perception* are interrelated, hence there is no clear and specific definition for each. *Spatial ability* can be defined as the mental process used to perceive, store, recall, create, edit and communicate spatial images (Linn & Petersen, 1985). Every person has spatial skills, however competency in understanding the surrounding space and the relationships and distances between volumes depends on various factors. According to Piaget, the development of spatial skills has three stages:

1. The first stage is when *topological skills* (2D) are developed. This occurs between the age of 3-5 years old.

2. The second stage consists of *projective skills* (3D): the ability to understand 3D objects from different viewpoints and usually acquired by adolescence.
3. The third stage, *Euclidean skills:* a combination of measurement and projective skills (3D). This entails an understanding of area, volume, distance, translation, rotation and reflection, combined with projective skills.

Hartman et al. (2006) suggest that spatial ability develops over periods of time, according to a person's development, exposure to various learning environments and life experiences. It has been hypothesised that through such experiences individuals choose to follow certain career paths. Following on from this, Lord's (1987) study found that women who have developed strong spatial perceptive thinking skills before college are more likely to migrate toward science disciplines than women with poorer spatial skills. In disciplines such as architecture, interior design, computer graphics engineering and medicine, which deal primarily with three-dimensional elements, students are required to have developed spatial skills. The ability to visualise three-dimensionally in the mind's eye is a clear indicator of educational performance and career success in these fields.

Psychologists suggest that spatial perception is not the perception of space as such but of the relationship between objects in space; they also believe that this ability can be largely learned (McKim, 1980). A number of contemporary studies has indicated that enhancement of mental image formation and manipulation is possible when students are subjected to carefully designed spatial interventions (Lord, 1987). Most of these interventions have been developed for students studying engineering and CAD (Gerson et al. 2001; Mohler, 2001), a few aim to help primary and lower secondary pupils to understand geometry (Christou et al. 2007) while others have been designed to help neurologically impaired children (Osberg, 1997).

1.3 Spatial Design Ability

The term *Spatial Design Ability* encompasses all the previous skills while also referring to the ability of designers to create mental models of their ideas and then communicating them to others through a medium (i.e. sketches, drawings, models, CAD models, etc.). Most interior design students are believed to have developed spatial skills; however a variation in competency in spatial abilities amongst them is expected. These skills also improve throughout the course of their studies although students do not get assessed on their spatial skills before they enter a course in architecture or interior design, at least not in the UK. The tutors believe that although a student with enhanced spatial skills will probably face fewer difficulties in learning a 3D software and creating digital models, that does not necessarily make him / her a good designer. Hence the term *spatial design ability* describes a combination of skills required from spatial designers.

Tom Porter (1979, p.61) in his book *How architects visualise* explains how design ideas are generated in someone's mind as mental images:

> *'Whenever the environmental designer is confronted by a design problem his initial solving process involves a visualisation of potential solutions. His creative imagination triggers a concept which is imagined ("seen") as a flashing dimensionless image with the mind's eye – images formed from his creative leap into the proposed environment […] Such a mental picture is a photographic impression – incomplete, in a state of flux and somewhat vague.'*

Designers can generate and develop images from concepts in the mind alone, however, these spatial ideas can become too complex to be contained within the mind and have to be externalised. There is, therefore, a need to transfer them into a tangible form in order to be clarified, assessed and articulated (Porter, 1979). Hence the creation of two or three-dimensional representations allows designers to experience the nature of their ideas and further develop them.

2. Visualisation Methods Used in Interior Design

The most common visualisation methods used in architecture and interior design practice are discussed below. Most of these methods are essential during the design process while some are utilised to ease communication between various parties. Apart from the advantages of each method, their limitations and drawbacks will also be raised.

2.1. Sketches and Drawings

As mentioned previously the design ideas or mental images need to be translated into a visual form first in order to be externalised, reviewed and refined, and second, to be understood by other people. Minah (2008, p.2) recognises three main stages in the design process: (1) the conceptual phase; (2) the schematic / form-making phase; and (3) the design development phase. Moreover he identifies two components that are central to the first stage: a formative idea or concept and a diagram that becomes an abstraction of the idea in drawing.

Therefore sketching and drawing not only help to bring abstract inner images into focus, they also provide a record of the advancing thought stream (McKim, 1980). Visual thinkers utilise seeing, imagining and drawing in a fluid and dynamic way, moving from one kind of imagery to another. Hence, sketching on paper is the first method that designers use to externalise their ideas as it is the fastest and easiest way to convert the ideas into a visual form. Additionally, specialised software and hardware offer users the ability to sketch digitally and then use the 'extrude' command to increase the height of the lines on the Y axis to create 3D elevations. Although there is ongoing research on developing tools to aid designers during the first stage of the design process (Dorta, 2004; Dorta & Pérez, 2006; Anderson et. al, 2003, Donath & Regenbrecht, 1996; Donath & Regenbrecht, 1999), this study focuses more on the intermediate and final stages; hence these projects will not be further discussed.

2.2 2D Plans, Sections, Orthographic and Axonometric Views

After the design has become more concrete designers naturally proceed to the creation of, hand-drawn or digitally-generated, 2D architectural drawings. In interior design the plans of the shell of the building or room are usually provided, whereas in Architecture students are expected to design the external structure as well. Hence the design briefs in interior design most commonly include the 2D plans and sections of the space. The assignment of a project starts by introducing the interior space that needs to be (re)designed in order to serve a specific function (e.g. office, restaurant, shop, residential, etc.). The orthographic plans provide an overview of the space's layout while offering detailed information about dimensions and distances between the structural elements. These are essential for understanding the configuration of an existing environment.

Students then create more 2D plans and sections of their own design that are based on the initial ones (Figure 6.1). These can be either hand-drawn or computer-generated (computer aided design – CAD), which is also the method preferred by most courses nowadays as it allows rapid changes as well as accuracy, portability and accessibility (i.e. the data can be sent electronically and shared between users).

Perspective drawings, such as axonometric or isometric representations, have been described as 2½D as they depict a 3D space but are in reality presented on a 2D plane (Whyte, 2002) (Figure 6.2). These include perspective representations of objects that are drawn from a particular angle. These are easier to produce when the plans of the space have been created digitally.

2.3 3D Physical Models (mock-ups)

In addition to drawings and CAD models, interior design students often create physical, small scale models (mock-ups) using cardboard, foam board, Plexiglas, clay, etc (Figure 6.3). This method is more time-consuming and costly than digital 3D modelling, yet it is actually the only method that delivers a three-dimensional model (since the 3D CAD models are viewed through a 2D monitor), though details and more organic shapes can be troublesome to construct. Moreover, due to the small size of the mock-ups, it is difficult for a viewer to understand the scale and the feeling of the space (Dorta, 2004). This is also referred to as the 'Gulliver Gap' where humans resemble giants observing tiny models of buildings / rooms (Porter, 1979). The small scale of the models has the advantage of offering a better overview but the disadvantage of not allowing viewers to be immersed and 'walk' inside the interior space.

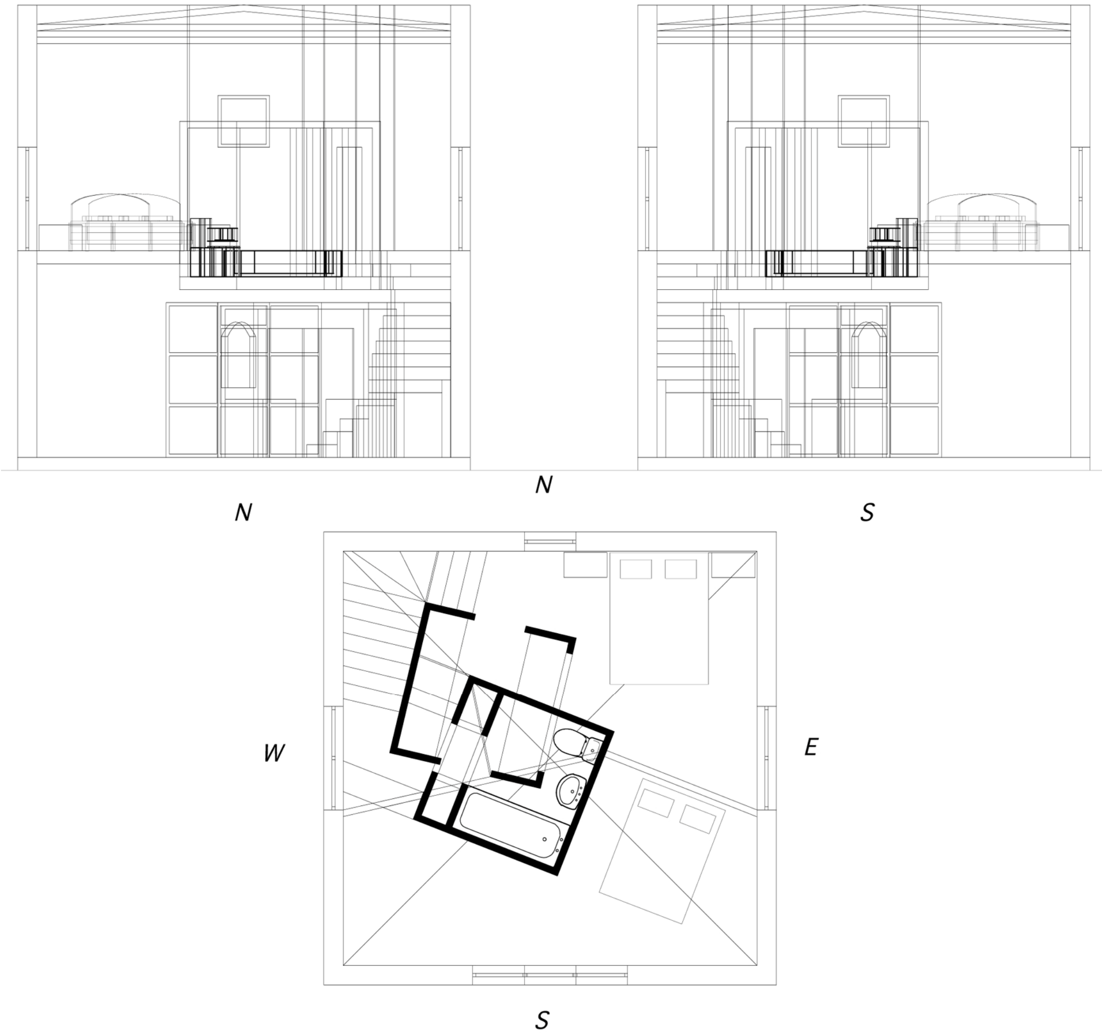

Figure 6.1: The image shows an example of a student's 2D architectural plan.

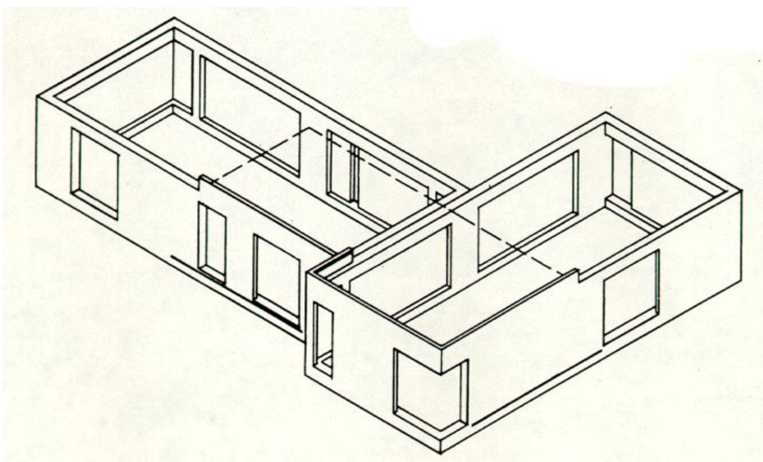

Figure 6.2: An example of an axonometric drawing

Prior to the advances in microelectronics technology, a technique to circumvent the 'Gulliver Gap' problem was to use a miniature periscope which it could be inserted into the models. A camera could be attached on the periscope to capture photos of the interior; nevertheless those images were of poor quality and distortion occurred around the edges. In recent years, the periscope has been replaced by micro cameras (camera tubes) which are inserted in the model and can either capture still images or record a video clip of a walk path. This method is usually utilised to study the light effects in a building. However, most of the visuals produced in this way again appear quite distorted and abstract. Often viewers cannot match the photo to the part of the model where it was taken from. Additionally these cameras can be expensive hence this technique is too costly and labour intensive while the results are poor compared to those produced by 3D computer models. On the other hand, physical models are ideal for communicating a design to non-experts (e.g. clients, public consultation). As such, detailed mock-ups are created for architecture or interior design companies undertaking larger projects while in educational settings the mock-ups are gradually being replaced with digital 3D models and animations.

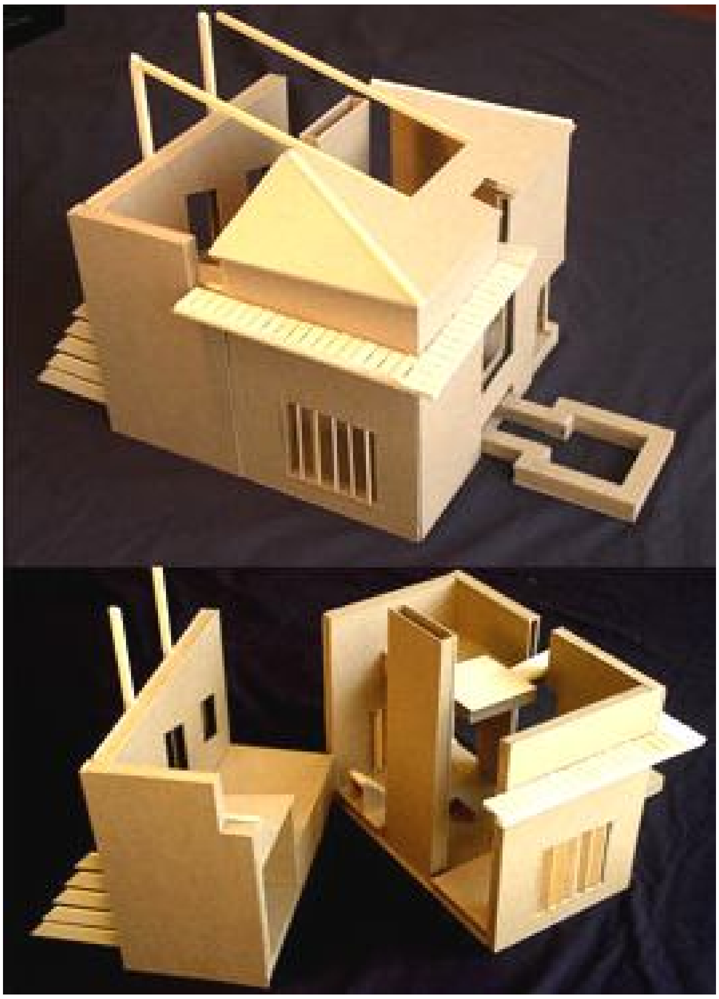

Figure 6.3: A 3D physical model (mock-up)

2.4 3D Digital Models

Nowadays most architecture and interior design departments introduce their students to CAD and / or 3D modelling software to produce the plans and 3D models of their designs. The benefits of using digital models are greater compared to hand-drawn plans. First, the 3D models can be easily and quickly created and modified, then realistic materials, textures and lights can be applied to produce high quality still images and animations. An example of a photorealistic 3D interior is shown in Figure 6.4.

Figure 6.4: A high quality 3D rendering of an interior space.

Digital 3D models are generated with the intention to convey the overall design idea, similar to the purpose of physical models: they are constructed to improve the perception of designs developed by drawings (Schnabel & Kvan, 2003). However, even though these models are created in 3D they are viewed through 2D computer screens, which eventually make them 2½D (Whyte, 2002). This means that the models can be manipulated three-dimensionally and thus viewers can perceive the depth effect, yet the screen is flat, similar to a piece of paper.

Furthermore they can be categorised as *static*, *dynamic* or *interactive* (Whyte, 2002, p 39). Even when the 3D model is viewed through the modelling software, from a number of viewpoints selected by rotation, panning and zooming, it is still considered *static*. Animations on the other hand are considered *dynamic* as they change over time (these are analysed in section 2.5). Models presented in VR, where the user can navigate inside the space in real-time and even interact with the surrounding objects, are characterised as *interactive*; these are presented in section 2.6, while a more extensive discussion regarding VEs in architecture and interior design is provided in section 4.

2.5 3D Animations: Fly-overs and Walk-throughs

After creating a 3D computer model and applying the desirable colours, textures and lights, the students can select a camera and animate it to follow a specific path inside or outside the model. The majority of 3D modelling packages support these basic animation techniques. There are two types of such animations: the fly-over and the walk-through. Fly-overs show the 3D space from an upward angle looking downwards (the ceiling is normally removed from the scene) providing in this way a general aerial impression of the area. This type of animation is more suitable for inspecting buildings and larger constructions as the viewer gets to see the model from a number of viewpoints. However, there is a certain loss in the sense of scale due to the absence of any effort required to move locations (Campbell & Wells, 1994). The 'birds-eye' viewing angle also seems unnatural since that is not how humans experience buildings in real-life.

For demonstrating a smaller interior space such as a house, a flat or a single room, a walk-through animation seems more appropriate. This time the camera is positioned at the average human height and moves inside the 3D model. Although some walk-throughs can be very realistic by imitating the walking motion and pace, the peripheral vision is restricted, especially when the interior space is small. The viewer is a passive spectator as he/she cannot control the motion or the direction of the camera as these are predefined. On one hand, high quality 3D animations can achieve an impressive level of realism with regards to colours, lighting, textures and reflections, but on the other hand the final outcome is not interactive. For the designer, and also for other viewers, this lack of interaction can be a major disadvantage (Achten et al. 1999).

2.6 3D Virtual Environments (VEs)

In recent years 3D VEs have been gradually making their appearance in architecture and interior design practice. The term 3D VE entails an interactive representation of a 3D environment that the user can explore through first-person or third-person viewpoint. The level of immersion in the environment depends on the type of hardware used (e.g. desktop monitor, semi immersive VR display, fully immersive Head-Mounted Display, etc.). Similarly, interaction with the environment can be achieved with various devices depending on the VE's complexity level (e.g. mouse, joystick, data glove, etc.) The technology is discussed in more detail in Chapter 3, while definitions of the technical terms can be also found in the Glossary.

Typically, Art and Design institutions will, in all likelihood, experience a 3D VE via a desktop monitor as it is cheaper, more accessible and easy to use, whereas more sophisticated immersive displays can be found in larger research laboratories, universities and a few architectural offices. One explanation for this phenomenon is related to cost and facilities, as larger institutions are more able to afford and house expensive equipment. Another reason is that close collaboration with staff or researchers from a computer science department is often required in order to develop and run an immersive VR facility, which is an obvious hurdle for art schools since they have limited or no in-house technical expertise.

Initially the main reason for introducing VR technology in architecture and interior design was to facilitate the final presentations. However, efforts have been made to incorporate the technology in the formative stages of the design process, from the sketch phase to 3D modelling. The social 3D virtual worlds, such as Second Life and Active Worlds may not be suitable for these disciplines, as the 3D models need to be converted in a format that the engine recognises and the level of detail has to be relatively low. Therefore, not all 3D designs can be uploaded in these 3D worlds. Hence, in the fields of interior design and architecture, the 3D models are being converted into interactive VEs instead of importing them in an already made and populated 3D world. Any 3D model created in a 3D modelling software package can be converted into a VE using a number of available VR authoring systems and toolkits Some CAD/3D software packages also offer a VR authoring application as an add-on. However, it must be stated that communication between the software packages is far from straightforward and the conversion of a 3D model into an interactive VE cannot merely happen with the click of a button. An explanation of the conversion process is given in this study. Given that this trial focussed on the use of spatially immersive displays and not desktop VR further analysis of the benefits and shortcomings of the former is provided in section 4.

3. Identify the Educational Problem

The visualisation methods described above have been used for many years in architecture and interior design education and practice. Nevertheless, they have limitations and thus may not allow for an inclusive and meaningful experience of the 3D spaces since users cannot study the space in full scale and often are unable to perform any actions, hence their involvement in the presentation tends to be limited. As discussed in Chapter 5, one of the main problems that the students and the tutors in this discipline face is the inability to present and respectively review the designs in actual scale. Therefore, even though these visualisation techniques help students to externalise and communicate their ideas, they often fail to convey the actual physical and aesthetic attributes of a space; the actual scale can be roughly estimated and the feeling of the space can only be imagined and not experienced. *'There is always the 'je ne sais quoi' that is so difficult to realise and communicate'* (Chadwick & Crotch, 2007, p. 145).

The ability to create an accurate mental image of the real three-dimensional space usually develops through experience and practice. Designers gradually acquire the skill of comprehending spatial data and issues, but this ability may not be as developed with novice and less experienced designers. Sketches, whether hand- or computer-generated, perspective drawings and CAD models *cannot* represent three-dimensional objects efficiently. As Dorta & Lalande (1998) have noticed, this intricacy stems from a basic contradiction: traditional design tools are two-dimensional while the topic under investigation is three-dimensional. Even physical models entail problematic issues because of their scale. 3D animations present the layout in a dynamic manner, yet the spatial attributes may be vaguely estimated and not fully conceived. Designers often may find themselves cut off from the reality of the work and this can lead to misinterpretations and design errors. Traditional tools use 2D media to represent 3D objects and only manage to introduce the third dimension in a limited manner; this affects the design process as well as the cognitive aspects that condition the designer's vision of the design idea (Dorta & Lalande, 1998).

Furthermore, the way information about three-dimensional structures is presented generates further difficulties and challenges for novice designers. Students are expected to be able to interpret abstract information, presented in the form of technical orthographic drawings and static perceptive views, in order to understand a 3D space. The creation and study of 2D plans and elevations requires a constant effort to encode and decode information transmitted through standardised symbols that the discipline uses. Often, it is assumed that students will be able to take that mental leap and naturally figure out how to encode and decode the information (Mohler, 2001). Yet even when students become familiar with the symbolic representation of 3D spaces, they still may fail to comprehend the three-dimensionality of the design (Schnabel & Kvan, 2003). For instance, in Study 2 a few students were not able to judge the scale of the room by simply looking at and reading the drawings, which is in agreement with this hypothesis.

Another limitation of traditional visualisation methods, in particular 2D ones, is the difficulty to create and communicate complex forms and details. Although 3D modelling helps to partially circumvent this issue, the effect of organic and perhaps unconventional forms cannot be fully grasped when viewed through a computer screen. For example, many modern buildings involving organic shapes and hyper-structures (e.g. Guggenheim Museum) have been built directly from ideas and designs generated using 3D computer software as these were too complicated to be drawn in perspective without compromising the fluidity and complexity of the forms (Dorta & Pérez, 2006). Yet again, the final visual outcome can be best experienced when the viewer is immersed into the space (virtually or physically) rather than seeing the 3D model through a monitor.

In brief, the educational problem is that although students learn how to read and use the symbolic language of 2D technical drawings, and learn how to create 3D models of their designs, they may not comprehend the actual scale of a space. Moreover, foreseeing the ergonomic and aesthetic qualities of a space only through the use of traditional visualisation methods can be difficult for novices. As interior design students do not have the privilege of constructing and experiencing their designs in full scale, other avenues should be explored to provide a life size representation of their design ideas.

4. The Proposed Solution

It is evident that both *Colour Experience* and *Spatial Understanding* studies shared the same educational problem hence the solution being proposed is similar. The **hypothesis** was that if students could explore their interior designs from within, in real scale using a VE viewed on a spatially immersive display, they could acquire an improved apprehension of that space and in effect enhance their spatial understanding. In essence, the intention was to offer students the opportunity to experience their designs in almost real scale and to observe whether this activity allowed them to understand the scale and spatial qualities of a space better than other visualisation techniques. The learning activity dealt mainly with spatial attributes such as scale, form and volume rather than colours and materials.

Even though many studies have evaluated the implementation of desktop VR applications, on various stages of the design process, only a few have actually tested spatially immersive displays. These studies have proven that even desktop VR can be more effective than traditional 2D visualisation methods alone in communicating a design, detecting potential problems and encouraging peer interaction (Paranandi & Sarawgi, 2002; Al-Qawasmi, 2005). Even so, the problem of conceiving the actual scale and feeling of a space persists with desktop-based VEs hence this study aims to investigate the use of spatially immersive displays.

The benefits of using such technology in this discipline are obvious and some even argue that architectural design has been the driving force for the developments in VR. Here I summarise some advantages of using semi-immersive or fully immersive VR technology:

1. *Working in three dimensions*

   One important advantage is that designers can work more three-dimensionally since every object within the VE is experienced through movement and interaction, and thus they are able to receive immediate feedback and get a better understanding of the spatial issues (Schnabel & Kvan, 2003).

2. *Giving substance to abstract information*

Often students use standardised measurements for door openings, width of corridors, ceiling height and so on. For example, the width of corridors and doors has to be wide enough to allow wheelchair access and students may choose to use the minimum acceptable specifications for these features without actually having a sense of how the space might feel. Dimensions provided on paper or on normal-size computer screen may not allow for an intuitive understanding of the space whereas an immersive VE can give substance to the numerical data by producing a life-size visual outcome. For instance, a technical drawing cannot communicate effectively whether a 70cm wide corridor will feel too narrow or too wide but when the space is viewed from the inside then the observers can get a better feel of it. It is expected that students can learn from such an experience and reflect on previous design problems when creating a layout in subsequent occasions.

3. *Better understanding of the designs*

The impact of an immersive 'encounter' with a design is powerful and aids to assess the spatial attributes and relations. People can better understand the effects of a design and can more efficiently assess the spatial organisation when they experience a VE (Achten et al. 1999). This was also confirmed by the findings of the *Colour Experience* study. A VE also aids communication between different parties involved (e.g. designers, clients, contractors, etc.) (Robinson, 2002).

Besides the visual aspects of a design such as walls, floors, ceiling and so on, designers and engineers can 'visualise' some non-material aspects such as thermal or acoustic isolation, structural stress, safety, etc. These can be directly mapped on the VE, in the form of colours, sounds or diagrams thus giving instant feedback to the viewer (Dorta & Pérez, 2006). The ability of VR to allow evaluation of the technical, ergonomic, aesthetical, constructional, logistic and other functional qualities of a design contributed heavily to its acceptance as a design aid tool (de Vries & Achten, 1998; Achten et al. 1999).

4. *Detecting design errors*

The technology can assist students to detect design errors more efficiently (Petric et al. 2001). Often, the lack of experience and / or the complexity of the designs can make the detection of errors somewhat problematic. An early mental model may not be flawless and thus errors are transferred throughout the design process without being noticed. Furthermore, studying a 3D model in an immersive VE can be an intuitive and natural process hence the users are able to notice details and issues as they would do in a real interior (Campbell & Wells, 1994). Given that everything is presented in real scale, even minor design weaknesses, which on paper would be difficult to spot, can become noticeable.

5. *Comparing design solutions*

   Studying design alternatives can be easier in a VE as the differences can be shown quite dramatically by switching between them (Achten et al. 1999). So whether a student has developed two design solutions and wishes to study and compare the impact of both or whether a tutor wants to contrast two or more students' design solutions to a particular space, VR applications support this capability.

6. *Material and Light Simulation*

   Advanced VEs can support the generation of real-time shadows, reflections and radiosity, which enables the simulation of light conditions and materials within an interior. This is a major advantage since perceptually, light, colour and form influence each other. Nevertheless, this technology is still too costly and may require close collaboration with a computer science department in order to imitate these phenomena accurately. This study did not involve real-time light simulation, materials and reflections.

7. *Virtual Reconstruction*

   The reconstruction of lost or inaccessible or preserved archaeological sites is another noteworthy application of VR in architecture (Paranandi & Sarawgi, 2002). The communication between archaeologists, historians and conservators becomes easier when the site is studied with a visual reference in mind.

So why has immersive VR not been extensively used in built environment education since it has so many benefits to offer? What are the issues that stall its implementation in educational settings?

In brief, immersive VR technology is still considered inaccessible and cost prohibitive with VR applications regarded as expensive to develop and challenging to operate and maintain (Horne & Hamza, 2006). Paranandi & Sarawgi's (2002) survey reported that desktop VR has been used successfully, almost daily, whereas immersive VR have not been widely diffused throughout the built environment industry and education. Most immersive VR architectural projects were conducted in the mid-nineties and they seem to have been either halted or spun-off into other application areas. Brooks (1999) reported that in 1999 there were approximately 100 immersive VR systems in daily use worldwide mostly in entertainment and vehicle simulation.

Fully immersive VR has not been widely used due to the many issues involved and highlighted numerous times by previous research (i.e. high cost, ergonomics, hardware performance, reliability, usability, etc.). Researchers have realised the demand for more affordable VR systems thus they have been experimenting with semi-immersive displays which are easier to use and more suitable for workspace environments in terms of size and cost. One such alternative system was the one utilised in the trial in the previous study. Nevertheless, it can be argued that even this semi-immersive VR system may not be cheap enough for an academic institution and that it requires a dedicated space and specialised equipment. So, although the active stereo semi-immersive VR system offered additional advantages compared to a typical desktop environment in the *Colour Experience* activity, the initiative to test the effect of a less expensive and sophisticated spatially immersive system rose. The findings of similar studies and the issues involved in setting up an active stereo display in the teaching studio urged us to exploit alternative solutions that could be more suitable for the interior design studio (in its current format).

Therefore, this study, apart from evaluating the use of a VE in a learning activity also compared two different displays: the semi-immersive VR display (as introduced previously) and a typical widescreen Wall Projection (WP). The obvious difference between the two environments was stereopsis. The cost of the displays was also a considerable difference. However, this was not mentioned to the participants, as cost should not influence their assessment of the displays. Even so, they could probably estimate that the WP is a cheaper system.

The semi-immersive VR display offers an enhanced feeling of immersion inside the virtual space through the stereo goggles, which produce depth perception by separating the image for left/right eyes; however it uses a smaller projection area than the WP. The widescreen WP by utilising two ceiling projectors uses a much larger projection surface that almost fills the user's field of view when he/she stands close to the screen. The comparative study intended to demonstrate whether a less expensive and easy-to-setup system can have the same effect as a semi-immersive VR system for this learning activity. The similarities and differences of the two displays are discussed in section 5.5.

This study has no similarities to those examining the educational impact of 3D graphics. Those studies mostly involve science topics and aim to provide a visual representation of concepts, phenomena, microscopic elements, etc. In this case the topic under investigation (interior design) is already visual therefore it is not a question whether visuals could be beneficial or not but what sort of visuals could be more beneficial.

5. Designing the Learning Activity

While the previous learning activity concerned the use of an immersive VE for colour education this activity focused on learning and teaching spatial qualities. Hitherto the implementation of VR for teaching colour has not been researched in depth whereas there seems to be a considerable amount of attempts to implement VR, mostly desktop-based, to study spatial attributes in architecture. Many articles have been published about their employment in architecture, but only a few have reported on results (Donath & Regenbrecht, 1999). Usually the relevant departments purchase the equipment and tutors encourage students to use them in their projects often without applying an appropriate work-flow and methodology. The outcomes of many of these studies remain unpublished.

Only a few studies have reported on cases where the technology has been carefully introduced in the curriculum and thus regularly and systematically used by students and staff (Achten et al. 1999; Horne & Hamza, 2006; Donath & Regenbrecht, 1999; Kalisperis et al. 2001). In terms of educational significance, a noticeable weakness that surrounds some of these studies is that they tend to be more technology-oriented than education-oriented. Most have measured students' mental and physical workload after the task to identify issues relating to usability and technological features; this method does not provide much evidence with regards to educational value.

This study aimed to gauge the students' and tutors' feedback and views about the use of an immersive VE during a particular activity: reviewing the 3D models of the students' designs. The idea was to adjust the technology to the needs of the course and not to change successful learning and teaching practice to suit the technology. As Fernades et al. (2006) argue, the participation of end users is necessary to better define the needs explicitly and increase the chances of having successful technology adoption. Hence this study was designed with the view to capture the participants' opinions and suggestions about the use of the technology as a design review tool. The following sections present the objectives of the learning activity, the educational theories applied, the learners who took part in the study, the 3D chosen models and the technology used in the trials.

5.1 Objectives

In this study, apart from educational objectives, I also introduced cost objectives as these have a strong effect on an institution's decision to purchase and implement the technology or not. Obviously, it is important to explore cheaper solutions that could provide similar educational benefits.

5.1.1 Educational objectives

The main educational objective of this learning activity was to enhance 2nd year interior design students' spatial understanding. An immersive VE is anticipated to ameliorate the problems of traditional visualisation methods by allowing students to explore their 3D models in larger scale which in turn should aid them to comprehend the spatial qualities of a space. With regards to educational value, this study attempted to answer the following questions:

Can this type of technology help students to understand and communicate the practical as well as the aesthetic elements of interior spaces more efficiently than traditional visualisation methods?
Can the experience of moving inside the 3D models improve learners' spatial awareness?
Can current learning and teaching methods be enhanced with the use of such technology?

This learning activity was designed along the same lines as the previous one thus the evaluation of the two displays was conducted using open-ended measures to capture the students' and the tutors' views during and after viewing the VE.

5.1.2 Cost and space objectives

The implementation of immersive or semi-immersive VR displays within Art and Design institutions is usually stalled by issues revolving around cost, space and technical expertise. Even though the cost of VR technology has been reduced substantially over the last years, it is still more expensive than one or two typical projectors hence one of this study's objectives was to compare two spatially immersive displays (a VR display and a widescreen WP) and evaluate their impact on the same learning activity. The initiative for the comparative study emerged from discussions held with the tutors of the interior design department as we were interested to examine whether a less sophisticated and expensive system could offer the same educational benefits.

Furthermore, space is always a problem for academic institutions. Inevitably, a stereoscopic VR display requires more space, given that a dedicated facility is desirable if not essential to host the equipment, whereas the WP option can be set up easily in most rooms regardless of their utility (e.g. meeting room, studio, common space, etc.). In essence, if similar educational outcomes can be achieved by both displays then it becomes apparent that the final decision will be influenced primarily by cost, space and technical expertise considerations.

5.2 Educational Theories

The educational theories applied in the *Colour Experience* activity have also been infused in the design of this learning exercise. Although the learning content was different, as this study dealt with spatial attributes and not colour, the learning and teaching method remain the same. However, this time, the activity was mostly led by the tutor of the course given that the intention was to carry out a typical design review session as those performed in the studio. Again, the idea here was to challenge the students' ideas and beliefs by showing them their own and their peers' 3D models through a different medium than the ones they have been utilising thus far. Moreover, as shown from the previous study, the oral expression of ideas, opinions and criticism between peers can aid to make concepts clearer and to prepare ones mind to accept the variety of alternative approaches.

5.3 Participants

Seventeen of the 2nd year interior design students who had taken part in the previous study, which employed the same VR display, participated in this experiment. The intention of recruiting the same group of students was that the majority of them were already familiar with the VR technology and the controls (3D goggles, joystick). It was anticipated that the students' previous experience of using the display would reduce signs of novelty and unfamiliarity and would allow them to focus more on the task rather than the technology. Another reason for choosing the same group of 2nd year students was the fact that their sense of spatial design ability might not be as developed at that stage (as it emerged from their responses during Study 2), therefore it would be interesting to observe how they had perceived or imagined their design and what was their impression after seeing it in an immersive environment. Furthermore, since the first term, these students have been learning how to use 3D modelling software (VectorWorks) so they had already created digital 3D models of their designs, hence it was deemed suitable for the purpose of this activity to utilise one of these designs.

One of the tutors of the interior design department also participated in the trial. His role was to conduct a design review session as he would normally do with the students in the interior design studio. His feedback on the potential of these systems for learning and teaching in this discipline was valuable as it was important to gauge the impact of the technology on the teaching staff. Hence, the tutor guided the review sessions and also participated in the group discussions.

My role in this study was similar to the one in Study 2. First I designed the learning activity after consulting with the interior design tutors and then I organised the trials. I gathered the students' 3D models, evaluated the surfaces, and added to them lights and shadows. Then the models were given to an experienced 3D programmer who converted them into interactive VEs. During the sessions I was taking notes while observing the participants, and I was also helping them when they encountered problems with the controls. At the end of the sessions I steered the group discussion by raising questions when needed.

5.4 The 3D Models: The Cubehouse Project

The content of this activity concentrated on scale, forms and volumes. Although this experiment was conducted during the third term, we decided to use one of the projects that the students had worked on during the first term: the *Cubehouse*. This project aims to help students develop their three-dimensional awareness and think about complex planning and relationships between spaces. The project brief challenged students to fit a three-storey two-bedroom house in a two-and-a-half-storey building structure. They also had to include pre-designed rooms for the bathroom and the kitchen (with the condition that the 'internal' cubicles should not touch an external wall), and a number of ready-made features such as pillars, staircase, lights, etc. Two perspective views of the complete Cubehouse model are provided in Figure 6.5. Note that this design brief focused primarily on the design layout and less on colours and materials.

Before the trial, the students were asked to revisit their Cubehouse model and correct / refine any potential errors it may have had. They were also advised to remove any high detail furniture to reduce the number of polygons and make the model lighter. Lights, colours and textures were also removed from the scene. All geometry had to be centred in the scene and a group containing only the transparent surfaces (e.g. window glass other glass panels) had to be created. The tutor collected all the files on a CD.

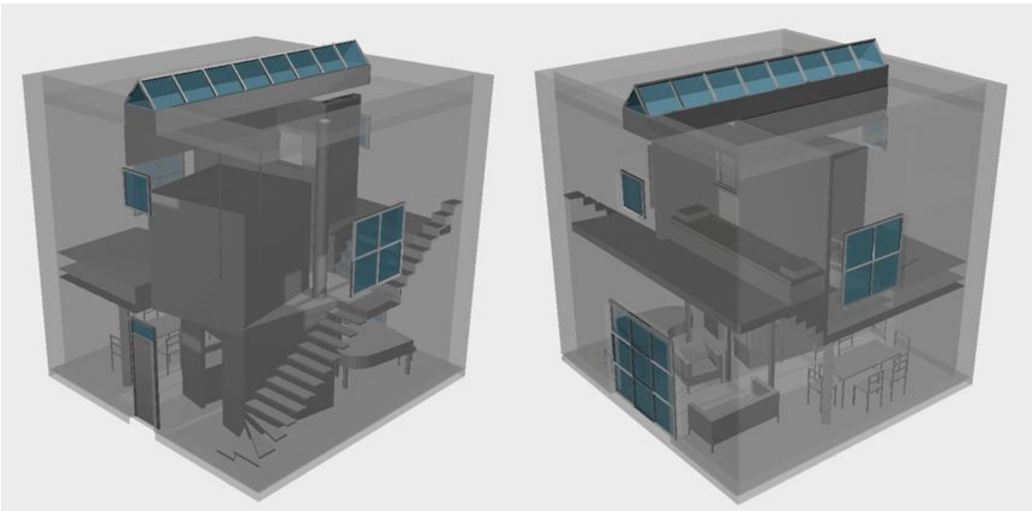

Figure 6.5: Two perspective views of a student's design of the Cubehouse project. The exterior walls were made transparent to allow the reader to view the interior layout. All surfaces, apart from glass panels, appeared solid in the VE.

The next stage was to import the models into another 3D software package (Maya) in order to evaluate the surfaces and to ensure a smoother import process of the models into the 3D application software (VEGA). Due to the absence of colour, lights and textures, the models looked 'flat' which was an issue that had to be resolved. The default colour of a 3D model, which has no colours or textures applied to it, is usually light grey and when the scene has not been lit there are no shadows and therefore no gradations of grey hence the surfaces appear flat and the sense of depth can be lost. Shadows are very important for defining shapes as they create a contour around them which separates them from each other. Objects can seem to float if there are no shadows to ground them. In addition, the absence of shadows blends the surfaces e.g. the floor and the walls appear the same tone of grey; this can cause disorientation during navigation inside the model. Therefore it was important to generate shadows for all the Cubehouse models to achieve the tonality variations. Figure 6.6 depicts a Cubehouse model without and with shadows respectively.

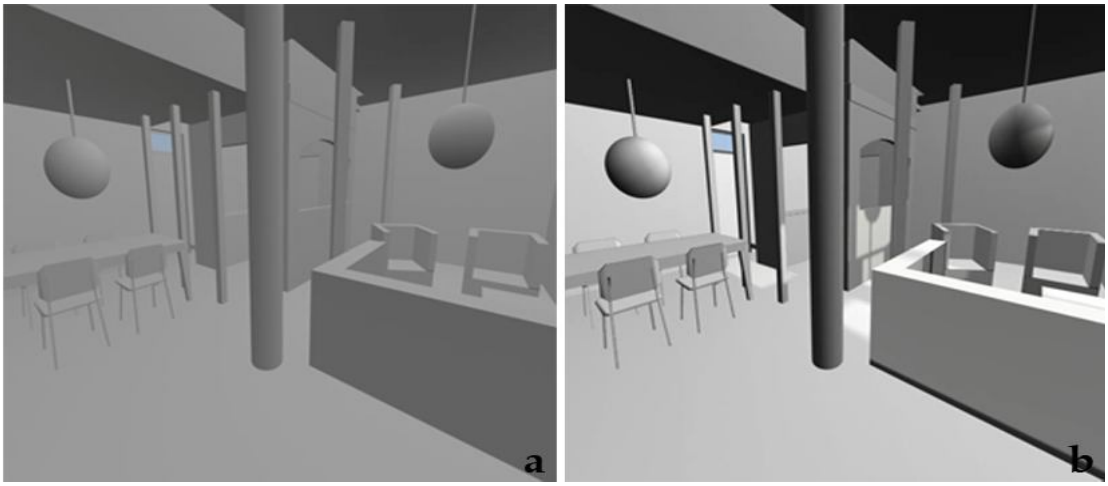

Figure 6.6: The images depict a view from within the Cubehouse model, (a) without lights and shadows and (b) with shadows.

However, the generation of shadows within the 3D application tool-kit did not produce satisfactory results as some surfaces became very white and others totally black. Furthermore, real-time shadows demand more computer processing power and hence navigation in the VE can become slower. The method that provided better control over lights' direction and shadow casting, and gave faster processing time, was the generation of shadows using a 3D software package (Maya). So, the student's models were imported into Maya and five lights of different intensity were placed around the building to cast shadows on the model. A technique called 'bake lights' was then utilised to burn these shadows on the surfaces. The computer calculates the amount of light that hits a surface and creates a texture which contains the shadow information for that surface. The amount of textures depends on the complexity of the model i.e. the number of different elements. In this way we can fake shadow casting, avoid real-time shadows and achieve smoother gradations. Nevertheless, this process had to be repeated 17 times, once for each student model.

Other issues arose during the export and import of the models between the various software packages such as flipped normals, missing surfaces, corrupt geometry, unfinished models, etc. Often, information may be lost during transfer between programmes, even if the file format is meant to be compatible. The corrupt surfaces had to be rebuilt otherwise they would not appear in the VE. Nonetheless, errors in the models that were caused by poor modelling (e.g. leaving gaps between floor slabs), or careless planning (e.g. lights hanging from the skylight rather than the ceiling) were not corrected as this was part of the learning activity: to review the models as the students had designed them.

The quality of the models was satisfactory but not photorealistic. The level of realism was adequate to communicate the designs and provide the means to engage the students. The interaction was limited to navigation inside the models thus no other virtual elements had been made active as this ability was not considered necessary for this learning activity. The refined models were then imported in VEGA. An external environment dome depicting a sky and ground terrain was added to the scene to create a basic external scenery so as to enhance realism.

Note that the intermediate stage (using a second 3D software package) is optional but in this case it provided better control over the technical aspects. Identifying the most efficient exporting/importing process usually requires a trial and error process as each software follows a different logic. Hence, here I presented the method that worked best for this specific experiment. However, it must be stated that this was by no means the only and easiest way to convert a 3D model into a VE. The conversion of the files and the generation of the shadows was not an easy process and it could not have been carried out by the students alone. If the system becomes available in the studio for the students to use daily then an easier process needs to be put in place. As a consequence, this issue became the focus of the follow-up study that is presented in section 9.

5.5 The Technology: The VR Display and the Widescreen Wall Projection

This study used and evaluated the impact of two spatially immersive displays: a semi-immersive VR system and a typical 2D widescreen WP, described here in turn. Both displays are considered immersive, nevertheless it was important to identify which display students considered more effective for reviewing the 3D models and whether depth perception or peripheral vision (fuller field of view) is more suitable for this particular learning activity.

The hardware specifications for the VR display have been provided in Chapter 5, section 5.6. The number of users of this display depends on the number of available 3D goggles and the size of the room. To reiterate the room that hosts the VR system is entirely black in order to avoid reflections and to make the screen stand out more. Figure 6.7 shows a student exploring her interior design using the VR display. The graphics appear blurred when viewed without the goggles hence it is unfeasible to take a clear photograph of this display.

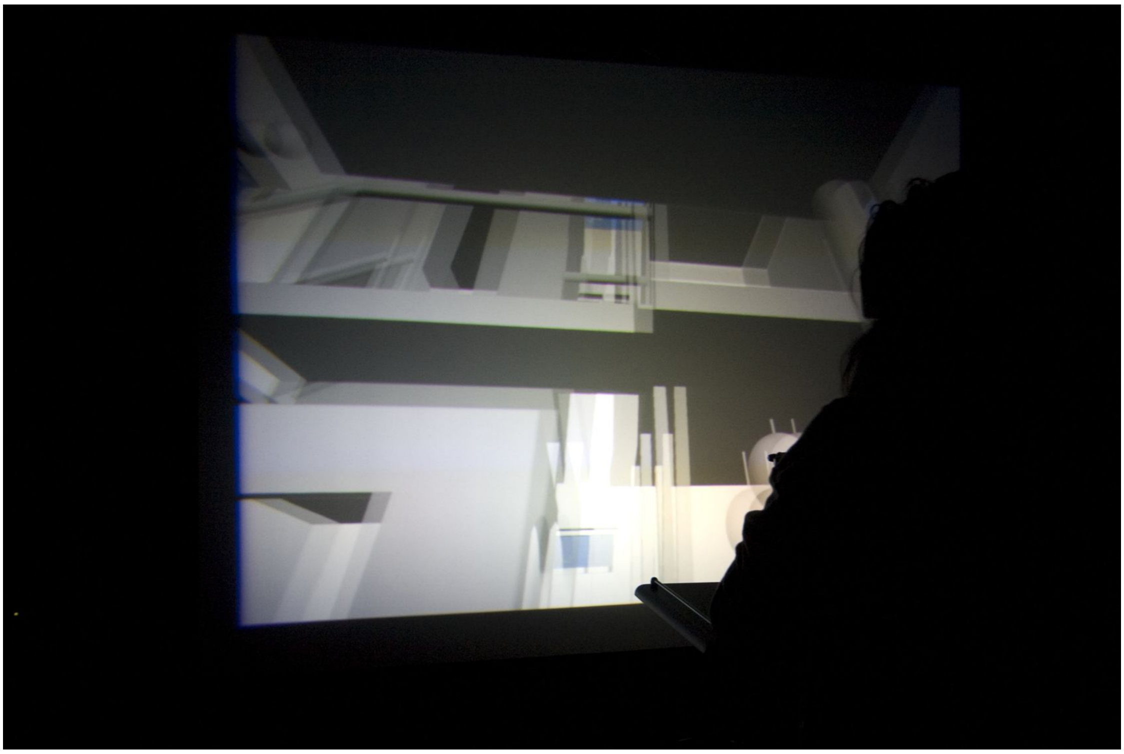

Figure 6.7: A student exploring her interior design using the VR display.

For the creation of the widescreen WP a wide display surface (4.4x1.65m) and two high-resolution ceiling projectors were employed (Figure 6.8). As this system used normal 2D projection technology, the students could see the VE without goggles. The large size of the screen, which fills a large part of the user's field of view it is assumed to compensate for the lack of depth perception. The amount of field of view covered depends on the viewer's distance from the screen; when the user stands relatively close to the screen the field of view coverage could be approximately 140 degrees. However the closer one stands to the screen the more difficult it becomes to get a full view of the environment (a holistic perceptive). Moreover, the size of the audience of the WP is only limited by the size of the room. Given that the specific space is normally used as a meeting room, its wall colour is bright (not black), and it can comfortably accommodate 30 viewers (although only those standing closer to the screen can feel immersed in the VE). Navigation inside the virtual world was achieved by using the same joystick as in the VR display.

5.6 The Structure of the Study

After deciding upon the models that would be used for this trial, the students were asked to refine their 3D models of the Cubehouse and save them in a specified folder. The models were then processed by the researcher and converted into VEs by an experienced 3D programmer, as described in section 5.4. The participation of the students and tutors during that stage was not required although the assistance of a programmer was again necessary, especially for operating VEGA, and for resolving glitches that required advanced programming skills.

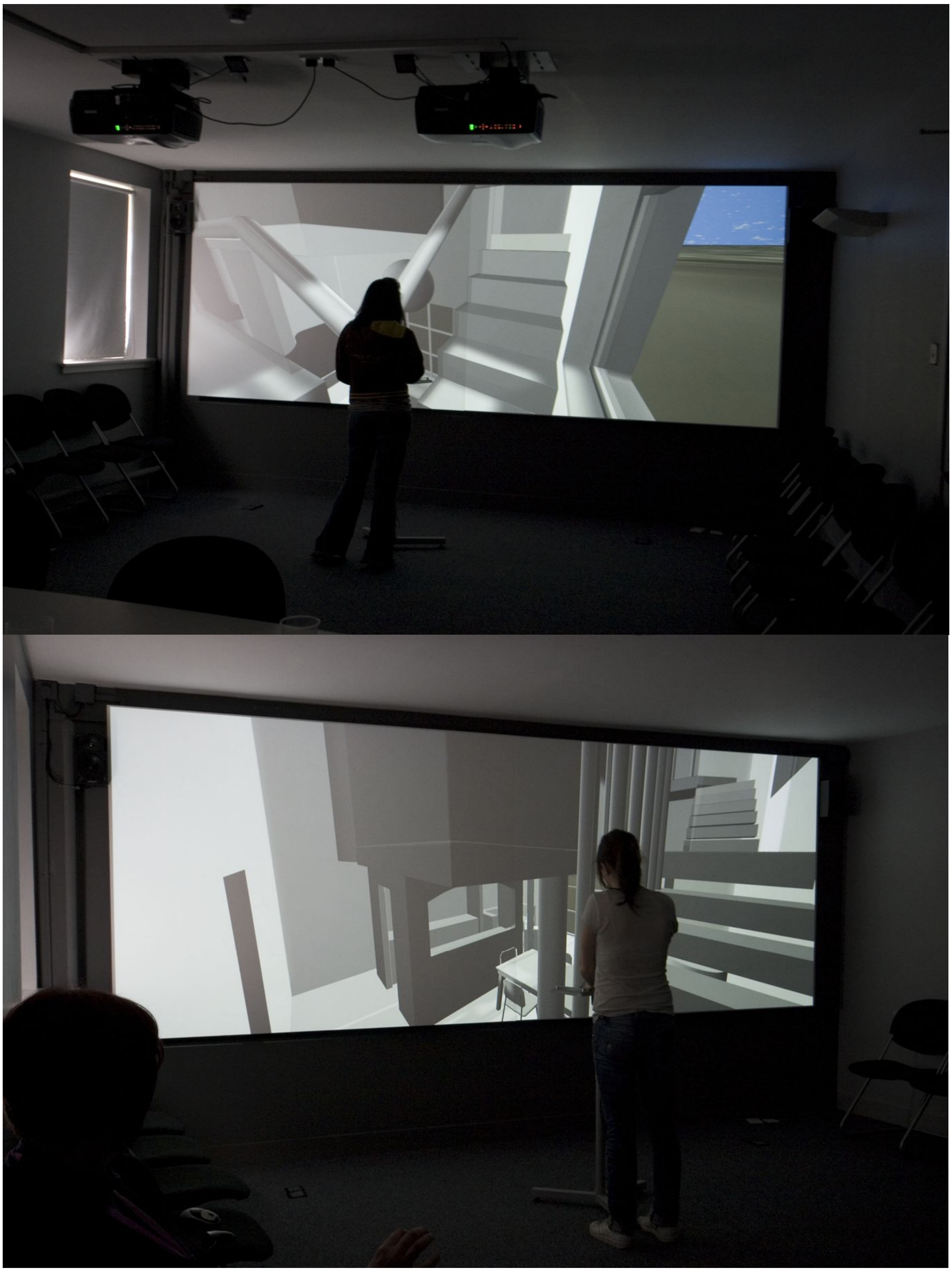

Figure 6.8: the photos show two students navigating inside their interior using the WP display. The top image also shows the setup of the system that employs two high-definition ceiling projectors.

The students had to travel to the DDS for the trial as they did for the *Colour Experience* study. Given that the VR system can accommodate up to six viewers at a time, the class was therefore separated into three groups who participated in the trial at different times: one group of five students and two groups of six. We opted for the maximum number possible so as to generate a livelier group discussion. The assignment of the students in the three groups was primarily influenced by the designs. To achieve a greater variety of solutions to the design brief within a group, dissimilar designs that followed an alternative approach to the design problem were clustered together. Nevertheless, another criterion that was less important, yet was taken into consideration, was the students' personalities. After consultation with the tutors, who were familiar with the students, it was decided to group students who would not intimidate each other since the contribution of all the students in the discussion was valuable.

Effectively, the trial involved four stages that all the three student groups went through. The first stage offered the students the opportunity to familiarise themselves with the navigation controls. For this purpose a simpler 3D model was utilised rather than the actual Cubehouse interiors. This training phase was carried out using the VR display. During the second and third stage each student explored his/her own design using both the VR display and the WP. The order of viewing the displays was intentionally not the same for all the groups as this provided additional information with regard to the familiarisation process and learning effects (Table 6.1). Hence, the first group initially viewed the interiors on the VR display and then on the WP, while both second and third groups viewed the WP first. Finally, the fourth stage of the trial involved a group discussion, which aimed to gather the students' views and thoughts about their immersive experience. Apart from the students and the researcher, a tutor from interior design participated in all three trials, during the exploration of the interiors and the discussion. It was important to record his view with regards to the learning and teaching potential of the technology and the impact it could have on his work.

Table 6.1: The table shows the order of viewing the displays for the three groups of students.

	Group 1	Group 2	Group 3
Number of students	5	6	6
Training model	VR	VR	VR
1st display	VR	WP	WP
2nd display	WP	VR	VR

6. The Study

Eventually 16 students took part in the trial as one student of the first group could not attend the test therefore the tutor navigated inside her model. The participants were initially led to the room where the WP was set up and were handed the consent form for the trial. I explained the stages of the trial and what was expected from them. They were told that they were about to explore the Cubehouse models using two different displays. They were encouraged to voice their views about the designs while they were exploring the interiors, whether it was their own or another student's. The tutor emphasised that they were not being assessed and that the aim of this experiment was to evaluate the displays and not their designs or their ability to use the navigation controls. The participants were asked to treat the trial as a design review session, similar to those carried out in the studio where they present their design idea to the tutors.

The groups were guided to the VR room for the training session. A simple one-floor interior with no colours or furniture was used for this purpose. After they were handed the 3D goggles the researcher demonstrated the joystick controls. Most of the students were familiar with the navigation controls from the previous study. Every participant navigated around the empty 3D interior until they felt comfortable with the controls. After this session a short break of ten minutes followed.

Each learner was given seven to ten minutes to complete the exploration which allowed for a reasonably slow pace and provided enough time for pauses to study elements that required more attention. Usually the participants watching the exploration would ask the designer questions related to particular features inside the space. Sometimes the tutor also raised questions about the designs and encouraged the students to offer their opinion about a design idea and perhaps suggest an alternative solution to a design problem.

As seen in Table 6.1, the first group used the VR display first and then the WP, while the order was reversed for the other two groups. A 20 minutes break was scheduled between the two display sessions. The order of the models was predetermined so the designer of each interior was called to navigate while the others observed standing around him / her. For all models the starting point for the exploration was in front of the entrance door inside the building.

6.1 Observations

The observations made during the explorations of the models using both displays are provided below. These have been categorised under five recurring themes:

6.1.1 Navigation

Depending on the layout arrangement some interiors were easier to navigate than others. For instance, narrow corridors and staircases were more challenging to traverse, and in some models the space between some pieces of furniture did not allow easy access. Some students were navigating better than others yet this ability was not solely informed by prior experience with video games controls. Those who were more gentle and patient with the joystick managed to walk inside the models at a slower pace without crashing into the walls too often. For a few participants crashing into walls or getting trapped around a tight corner caused them frustration and a couple of times they would ask for the researcher's assistance. The fact that their navigation was being experienced by other viewers made some of them more nervous. Although almost everyone encountered minor navigation issues, especially at the beginning of each task, a few students became too conscious of making their audience dizzy.

6.1.2 Scale

Most students expressed their surprise about the size of the interiors. The majority had imagined the space to be bigger than it appeared in the VE. The scale of the virtual interiors was relatively close to their actual scale. Note that neither display can guarantee a precise representation of the actual scale. In addition, many other factors should be taken into account, mostly related to human vision and perception, but for the purpose of this study this level of precision was not considered crucial. Besides it could not have been achieved with the technology that was available and it would have required software development knowledge. However, many researchers have been comparing perception of the spatial .layout in real and virtual environments. There is ongoing research to minimising this divergence (Arthur et a. 1997; Interrante et al. 2006; Thompson et al. 2002; Loomis & Knapp, 2003).

On one particular occasion the students made a comment about the width of a corridor as it seemed too narrow to them. We asked the designer of that interior to tell us what the width was: 70cm. A 70cm wide corridor, when it is also long would probably feel claustrophobic in real life, but the drawings or the 3D model do not convey that feeling. We also used a measuring tape to demonstrate the width and compare it to the visuals seen in the VE.

Comments were also raised about some furniture/features which appeared bigger than they should be. For instance, some students had chosen to place a piano in the living room space. Since this interior was fairly small the addition of the piano provided an extra challenge. In one of the models the piano was too big. The designer must have imported the 3D model of the piano into the scene and then increased its size without considering its proportional relation to the rest of the interior. This issue had not been highlighted when the 3D model was reviewed previously in the studio, but by walking inside the VE everyone could spot the problem.

Similarly, in another design, the railing that ran along the stairs and interior balconies was very big. The tutor explained that the size of the railing had been increased because when it was smaller it did not appear in the print-outs. He mentioned that often there is a need to exaggerate some features as otherwise they would not be visible on paper. The student neglected to revert the railing back to its normal size when she submitted her model for the trials.

Another example of size and proportions issues was the small second bedroom of a student's design. This was noticed by all the viewers and the designer seemed surprised by the size of it too. He admitted his concern about having designed this room a bit too small but he did not expect its effect. Only when he experienced the real-size visuals did he realise that probably his design had to be reconsidered as the space felt too tight.

6.1.3 Complexity

One design in particular triggered many questions and gathered mixed comments from the participants. This interior was very different from the others as the student had attempted to fit 4½ floors in a structure originally destined for 2½. The layout had influences of Japanese style interiors. The students were very interested to view this interior as when they had previously seen the plans and the CAD model they could not conceptualise it. Even the tutor commented that it was the first time he fully understood the concept of this design.

6.1.4 Comfort and facilitation of group learning

After observing the participants using both displays it become evident that the WP was more comfortable for the audience than the VR display. The main reason for that is the difference between the two physical rooms where the displays are hosted. The VR room is dark and smaller while the room where the WP is set up is much bigger and brighter. The students could sit around the table if they wished and watch the exploration from there, while they were also able to keep notes; this task in the VR room is somewhat difficult. Furthermore, since the WP room was not completely dark the participants could see each other's faces and expressions. These issues were expected to influence the outcome of the comparative study as the physical environment can have a significant effect on facilitating learning and teaching.

6.1.5 Glitches

During most preliminary trials that involve technology, as in the one described here, technical problems often occur whether they are caused by the hardware or software. This trial also diagnosed some glitches that could be fixed if the system is properly installed in the studio. Interestingly though, one of the problems the students encountered could also be used as a feedback mechanism. The problem was identified while a student was navigating on the first floor of her interior and she suddenly found herself on the ground floor. The transition was very abrupt as if she had fallen through a hole in the floor. This happened due to a very small gap on the floor, between the top step of the stairs and the floor. The system was not intelligent enough to recognise that the user in real life cannot actually fit through this tiny opening. Even though collision with the surfaces had been set, to constrain the user from walking through walls for instance, at the time, the virtual representation of the user in the VE, had no volume thus he/she could go through small gaps that may have been formed between surfaces. This technical issue, which can be potentially fixed through VEGA, added an extra difficultly for the users whose models had gaps since they had to be careful not to step on the gap while navigating. These openings were not visibly noticeable so only when this phenomenon occurred it became apparent that they were present.

This initially was considered a glitch that needed to be fixed however it provided feedback on the accuracy of the 3D models. These gaps should not have been present neither on the architectural drawings nor on the 3D models; usually all surfaces should be aligned properly. So, if students were to be assessed on the accuracy of their plans and modelling skills then this somewhat peculiar feedback mechanism could demonstrate to them where the faults might be. In this discipline, although precision is desirable it is not one of the most important aspects. This feedback function could be more valuable in disciplines where precision is crucial (e.g. Ship, submarine and aircraft design).

Another similar problem related to ceiling height. When the models are converted into VEs the viewpoint is set to an average human height i.e. 1.80m. Therefore if the ceiling is lower than that height the user will not be able to navigate properly within the interior considering that the application did not offer bend or crouch actions, similar to those that computer game characters perform. Nevertheless this was not a big drawback since only one 3D model presented that issue (close to the staircase) hence the viewpoint for that model had to be set lower. However, that also implied that the interior was not carefully designed. If the occupants need to lower their heads when climbing the steps then obviously the design has weaknesses, which may not have been noticeable on the drawings or the 3D model.

6.2 The Group Discussion

After the participants had reviewed the models using both displays they sat around the table in the WP room where the group discussion took place. The questions were addressed to all the participants as the aim was to hold an informal discussion about their experience, the learning activity and the comparison of the two displays. If a reply required further explanation the researcher would raise another question so as to encourage the participant to expand his/her argument. The following questions were used to direct the discussion:

1. Did your interior look different on the two displays? If yes, what were the differences?

2. Which are the strengths of the VR display? Which are the weaknesses of the VR display?
3. Which are the strengths of the widescreen WP? Which are the weaknesses of the widescreen WP?
4. Which display do you think was better at conveying the actual size of the interior?
5. Would it be helpful to view the models from the inside while designing an interior?
6. Is it easier to identify a design's strengths and weaknesses when navigating inside it?
7. How, if at all, did your understanding of your design or your peers' designs changed during the whole process?

The duration of the first group's discussion was 38 minutes; the second's was 26 minutes while the third's was 18 minutes. The first discussion lasted longer than the others as the tutor voiced his views during that session, while in the subsequent sessions he only added to the discussion when needed. Moreover, it was also a learning curve for me as after the first session I learned how and when to raise a question. Selected quotes from the discussions are provided and analysed in the next section.

7. The Participants' Responses

During the group discussions with the participants various themes emerged including sense of scale, immersion in the VE, navigation problems, design issues, detection of mistakes, suggestions for the implementation of a similar system in the interior design studio, etc. The fact that the tutor was present during the discussion aided the conversation as he provided clarification when needed since he was more familiar with the students and their work. Although section 7.1 offers mostly the students' responses, the tutor's input on the specific topics has also been included (referred to as IDT). A more detailed account of the tutor's feedback about the experience of using a VE and how this may affect his work is provided in section 7.2.

7.1 The Students' Responses

Given that the aims of this experiment were twofold (explore the use of immersive VEs in interior design education, particularly for studying and reviewing 3D interior models, and compare the impact of the two different displays on the learning activity) the students' views, as gathered from the discussions, have been categorised initially according to these two aims. Therefore, section 7.1.1 discusses the comments related to the effectiveness of this type of technology as a design review tool, while section 7.1.2 presents the personal preferences and opinions regarding the two displays.

7.1.1 The impact of using an immersive VE on the learning activity

Four recurring themes emerged from the participants' comments about the effectiveness of this immersive VE in studying scale, form and volume:

- perception of scale;
- better understanding of the designs;
- detection of design strengths and weaknesses; and
- implementation of an immersive VE in the design studio

However these themes are interrelated. For instance a wrong estimation of scale can also be considered as a design weakness, and gaining a better understanding of a design may lead to the discovery of potential errors.

7.1.1.1 Perception of Scale

As mentioned previously, the students expressed their surprise about the scale of the interiors as they seemed quite small and tight to them. Even though they were aware that the size of the building shell was not generous, it was only after experiencing the 3D models from the inside that they realised the actual size of them.

> *'You realised how tight it was. We expected it to be small, but now we realised how small it is, especially upstairs.'* IDS16

> *'The VE gave me the impression of being inside the space. And if you take my small bedroom for example, and put everything into context, then you understood how small that was. Yes I knew it would be quite a tight space but I couldn't understand how tight it was going to be and the VE helped with that […] it helped me realise that maybe I shouldn't have done that, if I had the choice again […] That is why I think it could be useful as a tool as it can help you understand your spatial limitations.'* IDS1

> *'…you get more like a real essence of "This is too narrow", "I'm getting a bit impelled", "I couldn't fit in there", "It's a bit claustrophobic" […] The VR display shows you the fact that there is not enough room, fact based of how would you feel in that space instead of how would you like that space to be presented.'* IDS8

> *'When you measure it you think that 2m is enough but actually walking through it you realise it's not enough.'* IDS15

> *'A lot of the spaces were narrower than expected.'* IDS14

The scale of the interiors as presented through the VE is in theory very close to their actual real-life size, nevertheless, the surprise of the students prompted me to ask the tutor whether the scale was actually representative. As explained previously in this chapter, the skill to visualise the size and dimensions of a space comes with experience, and probably for 2nd year students may not yet be so developed therefore the input of an experienced designer was valuable at this stage.

'The space was very, very tight in reality. Everything was designed with the minimum specifications, even the staircases were 70-80cm wide. That [the representation of the interiors in the VE] *is pretty convincing. It's difficult to tell however, to conceptualise the actual size but definitely the relationships between sofas, bed, and walls are realistic.'* IDT

All participants recognised that seeing the interiors from the inside as opposed to viewing them on the computer screen definitely gave them *a clearer perception* of the overall scale, dimensions, heights and relationships between structural elements and other objects. In the immersive VE they could see all the features in relation to each other and in relation to their own virtual 'height', thus they could observe the voids and gaps formed between the various elements. Most importantly, as student IDS8 said above, it gave them a sense of how the space would feel and not only how it would look.

7.1.1.2 Better understanding of the designs

All participants, including the tutor, agreed that the immersive experience gave them *a better understanding* of the interiors. This was even more evident for designs that were complex and unusual. It is often difficult to communicate complicated ideas through 2D drawings, plans and sections. An example of an unconventional Cubehouse design was discussed earlier in the observations section; the quote below refers to this design:

'IDS11's model had 4½ floors while everyone else's had 2½, so even if you did many sections it would be difficult to understand the design even if you know how to read the sections.' IDS8

Even the tutor agreed that seeing this model from the inside gave him a better understanding of the space. The majority of the participants only had a rough idea about that design and they actually understood the concept better when they saw it in the VE.

The VE made it easier for students to present their design to others as they controlled the exploration and paused when and where they wished in order to get a better view of the space. For instance, one model had internal windows between the different rooms which offered a see-through view from the one side of the building to the other. Although, the student who designed this interior had done this intentionally, she acknowledged that she had not exactly imagined the impact of this concept until she saw it on the displays.

Likewise, the audience got to discover this during the exploration as they had not noticed it in the drawings or the 3D model. She added that the external environment scene (sky and terrain) played an important role in this too as it made it more real:

> *'…the sky view added a lot to the illusion. It was good to get a sense of the inside and the outside which we don't get in VectorWorks. I think that was very helpful.'* IDS14

Hence, the process of explaining and demonstrating the design decisions could be considered less frustrating for the designer with the use of the VE as everyone sees and interprets the same visuals, whereas in plans and sections some details might be missed or not understood by the other viewers.

> *'You see views that you wouldn't normally see in the actual CAD programme.'* IDS1

> *'It would take you a long time to render these views with the software, while here it was very easy; you just glanced up and you could see everything. That was very good. I don't know if an animation would have worked the same way.'* IDS16

> *'It gave the opportunity to get views of the space you wouldn't normally get on the drawings because you do the plans and the sections and you select certain three-dimensional viewpoints to work on and I think we stumbled across views…I think IDS18's one particularly was pertinent as you have many degrees of visibility and voids and gaps and what it allowed you to do was take those views, and discover those views, by accident as an audience.* [Addressing the comment to IDS18] *you might have been looking very specifically for them but I saw bits that I hadn't expected which was quite nice, it was enjoyable to see where you always tried to get at.'* IDT

7.1.1.3 Detecting design strengths and weaknesses

Evidently, the ability to explore an interior from within helped students to *identify strengths and weaknesses* of the designs, which they may not have had considered before or noticed in the 2D drawings and the 3D model. Often structural details in the 2D sections might not appear in context and their connection to other elements might not be as obvious, whereas in the immersive environment it is much easier to see the whole interior through the enhanced peripheral vision. For example, one student had placed a light in the wrong place (the light appeared to be hanging from the glass of the skylight), however, he had not noticed this mistake when working on the CAD model. An explanation for this mistake is that when creating the models in the 3D programme it is easier to see the space if you remove the ceiling, hence students tend to make the ceiling surface invisible during this process.

The majority of students detected similar minor problems with their designs (e.g. the walls were not properly aligned, the corridors were too narrow, the steps had gaps, the pillars were not grounded to the floor, some rooms were too small, furniture looked too big for the space, etc.). Interestingly, even the slightest mistake in the model became very noticeable in the VE. The students were asked if they spotted any flaws in their designs:

'I wouldn't probably change the design idea but in both displays you noticed things that haven't been done quite right, little things like that.' IDS19

'My spare bedroom. I knew it was going to be quite small but now actually I realised how small it was.' IDS1

'One light was too big for the height of the ceiling. I would fix things like walls aligning up or gaps, which I couldn't see in the drawings.' IDS2

'My steps. When I was designing it I thought it could be a bit dangerous but I hadn't realised it until we saw it in the VE. It was helpful to see where your design had a problem.' IDS16

A couple of participants said that when this project was created on the computer they had just started learning the software, hence it was expected that mistakes related to 3D modelling would be present. Most believed that in the third term (the time the trial took place) they would not have made those miscalculations as they knew a lot more than they did in the first term. Therefore, when they were asked whether they would change anything in their design as a result of seeing it in the VE they replied:

'If I had the opportunity to refine the design I would not because I had experienced it in VR but because now I know more things.' IDS21

'I don't know if I would change anything because of the VR experience. I would probably change the things that I knew I didn't like from the beginning.' IDS12

7.1.1.4 Implementation of an immersive VE in the design studio

Some questions raised during the discussion intended to gather the students' views on whether this type of technology would be useful to have in the studio. Ideas regarding how and when they would prefer to use it were welcome (i.e. at the start of a project? during the design process? for presentation purposes only?).

'As we don't do any site visits it would be helpful to see the shell or the empty building before starting a project. You would have a different understanding of it or a different way to go about it.' IDS1

'While designing it. Because I would have seen the problem with my stairs.' IDS4

'I imagine using both [displays] *for presentation and not for testing out things.'* IDS12

'I think the VR display is more like a tool for the designer to experiment, to find where it works and where it doesn't and the second display [WP] *could be used mostly for presentation to clients as you don't need to give them as much information.'* IDS8

The above quotes demonstrate that the students' opinions varied on this matter. It is however premature to predict how and when the system will be used when it becomes available in the studio. This requires a long term study to identify the most appropriate and effective use of the technology. Only through observing and evaluating daily in-house usage by both students and tutors this question could be answered more fully. The intention here was to get a flavour of what the learners expected to happen in the future.

However, one student expressed scepticism about the implementation of such technologies in their education. Although he enjoyed the experience and recognised the aforementioned advantages, he expressed his concerns about the impact that these technologies might have on their creativity and consequently on their practical work. He argued that even though the VE conveyed the size of the interior better than the computer model, and provided a more holistic view of the space, it would be wrong for students to rely entirely on these displays. Moreover, he felt that the use of the immersive displays during the design process might limit creativity and imagination. As most problems could be detected and corrected at an earlier stage the element of surprise would be removed from the learning process. He also said that knowledge is gained through a process of discovery (trial and error phase) hence it is important to experiment and learn from the mistakes rather than preventing them.

> *'I think it could be a good thing to have while you are in the design process, it helps you understand different elements, but at the same time I think it could restrict what you are doing as well because you can see how things will appear which could restrict your imagination in a way. You would have to think harder on how to do things and you can maybe lose that process. If you use these technologies too much then you learn to expect what you will see and there is no element of surprise. It could be also dangerous to rely on it.'* IDS1

Another student felt that the depth perception of the VR display could distort the actual perceptive view and therefore she would prefer to view the plans alongside the VE to get a better idea of the layout and the exact dimensions. Most students agreed with this view. The VE was never meant to be used as a standalone review tool; it was not developed to substitute the other visualisation methods but to supplement them.

One participant commented that the experience could be further enhanced with the use of sounds, whether ambient sounds that provide information about the size of a space or sound effects, such as footsteps, so as to hear the different surfaces. She also suggested that lighting is very important in this discipline and a more accurate simulation of light inside the building throughout the course of a day (e.g. different sun positions) would be desirable. Such simulations are usually available via advanced 3D architectural software packages; further development of the system could include this function, however it would require additional programming.

7.1.2 VR display versus widescreen Wall Projection

This section elaborates on the strengths and weaknesses of the two displays as seen from the students' perspective. The comparison was based on their experience navigating within the same interiors using both displays. The points of reference were: representation of scale, usefulness in reviewing the models, navigation, immersion, implementation in the studio and lastly personal preference.

The perception of depth in the VR display was particularly favoured by the following five students as it allowed them to better grasp the spatial relationships (heights and widths). Even though they thought that the VR display conveyed the actual scale of the interiors better than the WP, the majority preferred the graphics in the WP. The wider field of view made the interiors appear more real and the movement inside them was considered more fluid, giving a more lifelike impression.

> *'I think the VR display was good in terms of the depth and it let you understand the heights and how far away things were better than the WP. The WP gave you a better peripheral vision which for me it made it a bit more real.'* IDS1

> *'You get a true sense of heights* [in the VR]*'.* IDS3

> *'I think the VR is more honest about the dimensions of the space than the WP. The WP gave us what we had already imagined in our heads: a false extra space that we had always imagined.'* IDS8

> *'I prefer the image through here* [WP] *because the screen is wider. The VR could make you feel more trapped as you don't have a full peripheral vision.'* IDS12

> *'The VR looks a bit more 3D, it gives you a better spatial awareness, but it could be a bit claustrophobic. The WP gives you a better layout of things. It was easier to locate objects.'* IDS21

In terms of immersion in the VRE, the VR display appeared to be more effective according to eight students. As mentioned previously, the entire room that hosts the VR screen is black; hence the surrounding physical environment is 'hidden' from sight so the users can focus more on the screen, which according to two students could be also a drawback since it caused eye strain. Three students regarded the two displays equally immersive. Nevertheless, the WP was considered more realistic even though students did not feel as immersed in it. An explanation for this is that people are more familiar with 2D projections (i.e. cinema screen, PowerPoint presentations, etc) thus familiarity potentially heightens the sense of reality.

> *'I think the bigger screen* [WP] *makes you feel more like you are inside the room than the VR.'* IDS4

'In the VR room a lot of things are going on and it's harder to concentrate on the task. However it does allow you to "jump" into the space while in the WP you still have the sense that you are part of another room.' IDS3

In terms of navigation, the discussion revealed that 'practice makes perfect'. As the size the interiors was small, the difficulty in navigating inside them was fairly high. As a result, many students bumped into walls and got themselves trapped in narrow spaces (corridors, staircases) which eventually caused them annoyance. A fast and spasmodic navigation pace created a more unpleasant experience for the audience than for the person who was performing the walkthrough. The students' responses regarding navigation in the two displays showed that their preference depended entirely on the order in which they experienced the environments. All three groups found that they navigated better in the second display, suggesting that this preference does not relate to the type of display but to the order they experienced it. One participant explained that she felt more comfortable navigating in the WP because it resembled interaction with a computer model.

'Navigation in the WP was a bit more familiar as it resembles the interaction with the computer even though we don't use joysticks.' IDS14

Two students experienced light motion sickness while exploring the interiors using the VR display. If the user's position is not correct (ideally at the centre of the screen), the goggles might lose the connection with the transmitter which results in switching between stereo and mono vision (flickering effect). This obviously can cause eye strain and subsequently motion sickness. One student claimed that the flickering effect can also cause disorientation.

'The VR made me a bit dizzy. But it's bearable if you take small breaks in between. The room was warm too. In this room [where the WP is set up] *I didn't have this problem.'* IDS16

'I think the VR seems more focused because you concentrate on one area so you get more motion sickness. While the WP is more spread out and it gives you a more lifelike impression of how you would move through a space.' IDS1

'You can feel a bit disoriented in the VR display because of the flickering as the image goes out of focus. Whereas in the WP, everyone is seeing the same thing and there is no flickering and you have more control over the presentation.' IDS8

'I think it's the disorientation, if you are moving swiftly your body responds in the VR while in here [WP] *is smoother.'* IDS3

All the participants felt that the WP was more comfortable and more pleasant to view for they did not have to wear goggles and they could just sit back and watch whereas the VR room felt slightly claustrophobic because of the smaller room which was all black. In the WP room, the students could sit around a table and watch the interiors while at the same time they could hold a discussion between one another or with the tutor about the design and keep notes if they wished. The dark room of the VR display may allow for a more immersive experience yet it is not ideal for performing other tasks.

'The WP was very comfortable as we could sit back and watch it.' IDS16

'The WP gave us the opportunity to sit back on the table, discuss about the rooms, it's more comfortable and familiar. The VR room because of the darkness and the paraphernalia makes it "something". Whereas I like the WP room, I wanted to bring the joystick on the table and navigate from here and we can talk about it and be able to discuss. It seems convivial.' IDT

Overall, the majority of the participants preferred the WP over the VR display. More analytically, 9 out of the 16 students preferred the WP, 5 preferred equally both while 2 had a strong preference towards the VR display. Even though the VR display offered them depth perception, a higher degree of immersion in the virtual world and the 'wow factor', it was not regarded as practical or as comfortable as the WP. Furthermore, they thought that the WP would be easier to set up in the studio.

'I prefer the WP because it's more comfortable for the eyes, more pleasant.' IDS8

'I think the VR one is more exciting.' IDS19

'I prefer the WP because it's more like a presentation tool. I can't imagine handing people glasses.' IDS12

'I liked the VR. But I liked the WP too because of the wide screen which is very important.' IDS11

'The WP felt more airy. The VR is more squeezed. In the VR you could understand the spatial dimensions better. The WP gave a better view of the interior. I prefer the WP over the VR.' IDS15

'I preferred the WP. It was a lot clearer or it might be the fact that I was feeling a bit dizzy in the VR.' IDS9

'I prefer the WP because it was more comfortable. The VR though felt more real.' IDS20

'I preferred the VR because it felt more real.' IDS17

Almost 30% of participants could not choose one display over the other as they could find benefits as well as drawbacks in both of them. They felt that both displays can be equally beneficial in terms of giving them two different representations of their design. A combinatory use of both displays could allow for a deeper and more thorough exploration of the designs.

'I don't see much of a difference between the two. I thought they were both useful. If I had to choose which display to project my design on I couldn't pick one out, I wouldn't mind which one I used. I would use either. Because you can never find the perfect programme, there are weaknesses and strengths for both of them but they weren't so dramatic.' IDS21

'I agree that the WP was more comfortable but the VR was more exciting. It could get better views by looking up or down.' IDS14

Although it was expected that the study would demonstrate a clear preference towards one display, it seems that the differences in the appearance of the VE on the VR display and on the WP were not significant. Clearly, the factor that most influenced the student's choice was the physical rooms the displays were housed in. This might be considered an external factor which is not directly related to the visual outcome. However it is nonetheless important and will be further discussed in section 8.

7.2 The Tutor's Responses

The tutor mentioned that he found the technology extremely helpful for understanding the designs and highlighting certain design problems to the students. On the other hand he felt that the displays were 'too honest' as most of the flaws could be easily identified. These flaws most of the times would probably go unnoticed in the 2D drawings. He also commented that the use of the CAD software from the beginning of the second year of the course was beneficial as the majority of the interiors were of high quality and most design issues have been spotted in advance, before the final review. The computer models are not as forgiving as the 2D drawings and apparently the VE is an even stricter critic.

'I enjoyed seeing the Cubehouse projects again and seeing them like that was an interesting experience. Genuinely to see the kind of quality of designs because it is an honest presentation of the drawings that you did [referring to the students] *and I was pleasantly surprised. The quality is there, in 90% of cases the issues had been resolved. This is the first year we carried out this project on the computer and I know for a fact that in previous years problems get pushed to one side when designing on paper as the students are asked to do three plans and two sections and therefore "that tricky corner in the back left-hand side" you can just ignore because you don't draw that section, you can get away with mistakes in 2D drawings. While that hasn't happened this time, so it became more obvious how resolved the issues in these projects were.'* IDT

Although this could make the assessment of the works easier and faster, there is a danger that the tutors could become 'lazy', which perhaps could be unfair to the students.

'What it did [referring to the VE on both displays] *was to highlight lots of little issues and big issues for good and for bad I suppose. As tutors we can become quite lazy though because we won't have to read any drawings since we can see the model and here it's very easy to see what is working and what is not working.' IDT*

However, the tutor identified another advantage of the displays: the ability to occupy and explore the 3D models as a group. This shared experience eventually better informed the discussion about the particular design. On the contrary, according to his experience, the solo experience of looking at a model as it is handed around can lead to potential ambiguity or misinterpretation of the drawings, thus the technology enabled a less-inhibited and productive dialogue, as comments were made based on the experience rather than speculation. In addition, everyone in the group can get a clear view of the model whereas during a crit session for example, some students get a very restricted view of the drawings under investigation, and reading line drawings from a distance can be difficult. This problem has been observed by architecture tutors as well (Chadwick & Crotch, 2007; Melles, 2008).

After steering the three review sessions during this trial, the tutor stressed that the use of the displays aided and enhanced this activity. He said the ability to quickly ask and answer questions regarding volume and space, and the opportunity to witness the impact of design decisions on the space proved very useful as a learning tool. In addition to the clarity and ease provided, it also achieved a more 'active' engagement of the students as it enabled them to feel more in control of the discussion. The conversation was therefore no longer wrapped up in a tutor's mysterious ability to read drawings, but was based firmly on the group experience.

The tutor had anticipated that the difference between the two displays would be greater since the VR display is more sophisticated as a system and obviously more expensive than the WP.

> *'The difference between the two displays is negligible, which I find a bit upsetting as I thought the difference would be greater.'* IDT

According to the quote below, the 3D effect that the VR offers can be somehow created in the viewer's mind when watching the WP.

> *'As a viewer you are capable of applying the depth to it* [to the visuals on the WP] *as I am used to reading drawings and because in the same format I'm used to seeing films, it's like being in the cinema. So I'm applying this reality filter to it rather than a printed picture where you go "This is a picture".'* IDT

His overall opinion about the systems was very positive and he considered them very useful for learning and teaching in interior design. In fact, his interest for the technology and its implementation in the studio prompted him to take part in a similar follow-up study, which is presented in section 9.

8. Discussion

8.1 About the Findings

The participant's feedback supported the conclusions drawn from the observations conducted during the trials. Furthermore, the findings of this study are also in agreement with the findings of other studies that have tested the use of VEs in architecture and interior design (Paranandi & Sarawgi, 2002; Schnabel & Kvan, 2003; Achten et al, 1999; Achten & Turksma, 1999; Dorta & Pérez, 2006; Campbell & Wells, 1994; Horne & Hamza, 2006, Kalimeris et al. 2001). The findings of the *Spatial Understanding* study were:

- Better understanding of the designs
- Detection of design strengths and weaknesses
- Enhanced spatial awareness
- Better communication of the designs
- Easier comparison of design solutions
- Improved review / crit sessions
- Easier assessment process
- Combination of visualisation methods
- Exciting and engaging learning activity
- WP over VR display

The first two findings have been extensively discussed throughout this chapter hence I will not analyse them further. They also confirm the benefits of VR technology in this discipline as presented in section 4 of this chapter.

Enhanced spatial awareness

The trials demonstrated that most students realised the actual size of the interiors after they saw them through the VE. They commented that everything appeared in context and they could understand the spatial relationships much better from being inside the virtual rooms. This again was not an unexpected finding as it has also been found in other research studies. Although studies in the area of human perception support that spatial awareness is a skill that can be developed further by proper learning exercises, this study cannot claim that the learners' spatial awareness in general was improved solely due to exposure to the technology. As explained in the beginning of this chapter, there are specific tests that measure spatial skills, however they do not seem relevant to the educational objectives of the learning activity presented here as they do not share the same philosophy. The activity aimed to provide the experience of spatiality rather than asking users to perform a series of spatial skills tasks. The tests mostly use individual shapes that do not appear in context whereas this activity dealt mainly with spatial relationships and analogies between various shapes. Therefore, testing whether the students' spatial awareness had been enhanced after the task by using these tests would not have been appropriate.

In theory, the following technique could have been applied to get an indication of the students' ability to estimate scale and dimensions: we could have asked them to complete a task such as '*Do you think that two 80x200cm beds could fit in this room?*' or '*What is the maximum table size that can be inserted in the dining area of the interior?*' Still, some students would be better at guessing than others, and the keyword here is 'guessing' so such a task cannot provide accurate results regarding someone's spatial awareness.

An approach, that is in line with the theories of constructivism and critical thinking seemed more suitable. Although no assessment of spatial skills competency was performed, I detected signs of surprise and conceptual change which in essence could be translated as little steps towards gaining a deeper understanding of the subject matter. According to Norman (1981), two things must happen for critical behaviour to be initiated: feedback must have occurred and divergence between expectations and observed events must have been detected. The personal experience inside a 3D space triggered the students' critical thinking by providing them with another perspective of the designs that they cannot receive via traditional visualisation means. The VE demonstrated the difference, if any, between the learners' 'expected' outcome and the 'actual' result. Their reactions (e.g. surprise, defensive behaviour, even self-criticism) could be seen as an indication that the VE made them re-think their ideas and analyse further the weaknesses they spotted.

Intrinsically, the participants' spatial design ability will develop through the course of their studies, with or without the use of this technology. The question that this study raised was whether the development of these skills could be accelerated by using a VE to study the designs. Nevertheless this cannot be answered by only one exposure to the system as a longer term study is required, with perhaps more frequent use of the technology by the students in the studio. Then comparison could be drawn to previous year groups in terms of advancement in spatial design ability. This again cannot be assessed through a questionnaire or a test as it is too vague and abstract to measure. Other similar studies have claimed that immersive environments have helped to enhance the spatial awareness of learners yet they do not provide any sort of solid proof. Perhaps a systematic observation of the students' work throughout the course of three years for example could show signs of improvement, however these should not only be attributed to the new technology since many other factors influence the development of these skills.

Better communication of the designs

It seems that students can perform a better presentation of their design to their tutors and peers by using this medium and the 2D drawings in conjunction. They have better control over the presentation as they can pause at particular areas be it because they wish to draw attention to them or because they encountered a problem and might want to ask for help and advice. Communication becomes more natural and straightforward. All the viewers see the same visuals, and misinterpretations are unlikely to occur as often as when only reading the 2D drawings. Hypothetically, that could make the review and the crit sessions less stressful and more effective for the students; sometimes stress is not only caused by the fear of performing in front of peers and staff and of being assessed, but by the inability to communicate the design idea successfully. Occasionally tutors might misinterpret a project and then the learner's frustration may rise as he/she attempts to defend the idea and change the tutor's inaccurate mental model. Although this discussion and 'negotiation' are part of the learning process in this discipline, an immersive VE could assist by making these debates more transparent and perhaps less stressful. As everyone shares the same experience of the design there is not much room for claims of unfairness with regard to the comprehension of the project.

Easier comparison of design solutions

An added benefit of exploring the designs in an immersive VE in groups is that viewers can draw comparisons of the designs much faster than from reading the drawings. The students get to see their peers' designs and draw conclusions about their effectiveness, similarities, differences, style, etc. In this experiment, the learners only got to experience six designs, as we split the class into groups; however, if the system is available in the studio the students should be able to review all their peers' designs during the same session. The diversity and breadth of design solutions applied inside the same building skeleton was not only fascinating but it was also an 'eye-opener' as it demonstrated the various design approaches to the project's brief, it generated discussions among the participants and perhaps even challenged their ideas. Through comparison the students realised which interiors were more functional, which were more aesthetically pleasing but probably less practical, which were more open-plan and which felt claustrophobic and so on. These contrasts cannot be easily made through traditional visualisation methods, hence that was another benefit that a VE offered.

Improved review/crit sessions

During a typical review session in the studio, the designs cannot be shared in the same manner, as the students standing further away may not be able to have a good view of the 2D drawings or of the computer screen on which the CAD model is presented. The tutor commented that the review session was easier to conduct with the use of the immersive VE as every one had the opportunity to view the same visuals. This generated a livelier discussion since all the students were engaged in the review. It was easier to ask or answer questions about a particular part of a design by 'walking' through it rather than viewing the 2D drawings or zooming into the 3D computer model.

Even though the literature review on Art and Design education picked up on issues related to the current format of crit sessions, especially when bigger groups of students are involved, this study had not intended to address these issues. Nevertheless the feedback showed that such a system can also improve the conduct of crits.

Easier assessment process

Since the reviews and crits are part of the assessment process in Art and Design, the technology can in effect make this process easier and more transparent for both tutors and students. The tutor can evaluate the quality of the models and detect the strengths and weaknesses of a design more easily than by only looking at the drawings. The tutor who participated in this study also mentioned that this could make the educators somewhat 'lazy' but probably fairer. Then again, given that most design flaws are noticeable in the VE, the evaluation of the projects could become too strict and not so forgiving. A way to counteract this issue so as not to be unfair to a new generation of students who may be using this technology in the future would be to give them the opportunity to use the system to review their models and then allow them time to refine them before the final presentation. In this way both students and tutors get to benefit from the advantages of the system with regards to assessment.

Combination of visualisation methods

To reiterate, the purpose of using this technology in interior design education was to enhance the current visualisation methods by providing a possible solution to their limitations. All visualisation methods presented in this chapter are important to the design process and in consequence to the education of interior designers. They all give a different perspective of a design and offer different information (i.e. the CAD drawings give information about distances while a VE can provide the experience of walking through the space). As this study showed, a combination of 2D drawings, 3D models and immersive VE is required to reach a better understanding of the projects. By reading the drawings one can get an idea of the layout of an interior very quickly whereas in the VE the layout is discovered during the exploration; however the walkthrough does not guarantee that users get a clear idea of the exact layout. Hence it is essential to view as many different representations of the design as available. During the trial, there were moments when students wanted to refer to the 2D drawings and unfortunately these were not available. I could have asked for the plans and sections of each model and have had them at hand as at times they could have been useful to have on the table while reviewing an interior. In the follow up study, it was ensured that the drawings were available to the students during the review session.

Exciting and engaging learning activity

In a nutshell, the learning activity offered students an exciting and enjoyable experience. The tutor noticed that some students, who are usually quiet, participated more in the discussion during the reviews and in the group discussion. From the students' feedback it became clear that they would like a similar system to be installed in their studio for them to use daily if they could.

Widescreen Wall Projection over VR display

While the VR display seemed to carry a more vivid sense of realism, presumably due to adding stereopsis, there was some indication that for these students, the wider field of view afforded by the WP contributed more to augmenting their apprehension of space. This can be seen as a more subtle sense of realism than direct sensory fidelity. On the other hand, it might simply be that the proportion of the visual field that can be filled is the crucial feature here, and in this study, the WP achieved a higher proportion than the VR display did (as the latter used a standard size and thus a smaller screen both in terms of absolute size and of visual angle from the students' position).

However, also clear from the comments is how the WP approach fits better than the VR with the group interaction traditional in and central to Art and Design education. The repeated use of peer commentary, and of crits performed with peers, designers, and the design in question, all taking place in the same space, allows for pointing things out to each other. The VR room was not considered convenient for conducting a review or a crit, thus the WP was favoured by most. The difference between the physical rooms was the criterion that determined the students' choice of display. From the participants' point of view the other differences between the two displays were not significant, given that almost 30% of them could not choose one over the other. Having both the VR display and the WP might be optimal for learning and teaching since they brought out somewhat different aspects of the designs, but if only one were possible or if value for money is a determining criterion, then this study suggests that the WP approach might be the method of choice.

This research tested only two display configurations hence further questions emerged after this trial with regards to what other systems could be suitable for the interior design studio. These are discussed further in the following section.

8.2 About the Study

In order to test the hypothesis of this study I followed the same methodology as in the previous one that involved interior design students. I conducted a trial that tested an ad-hoc use of a VE during a design review session similar to those performed in the studio. Here I reflect on the various aspects of this study and discuss how the lessons learned informed the framework for the follow-up study presented in section 9.

A **learner/tutor-centred approach** was applied to evaluate the impact of the displays on this learning activity, hence open-ended measures such as observations and group discussions were used to gather the participants' feedback. It was important to involve the participants in the evaluation process as they are meant to be the end-users and therefore they should be able to judge whether an immersive VE could be beneficial for their education or not. This time, I decided not to utilise questionnaires as in the previous trials some participants expressed their dislike for questionnaires, in particular open-ended ones. In addition, although questionnaires could have provided some additional information, they were not considered necessary. On the other hand, a rating scale could have been useful for assessing the individual features such as navigation, immersion, precision and preference for example. This was implemented in the follow-up study.

The particular system is not meant to be a design tool but a **design review tool**. If the students wished to make alterations on their designs using the system in its present form, they would have to revisit their model in the 3D software package (VectorWorks) and save and import a new version of it in the VR authoring software (VEGA). The ability to move or assemble elements (walls, staircase, furniture, pillars, lights, etc) was not entertained at the time, thus the design could not be altered while being inside the VE. Some computer science studies have focussed on implementing the ability to perform these actions within the virtual world, but there are many limitations that hinder the development of a fully interactive real-time VE (Calderón et al. 2006). According to these studies, the designers are able to perform more intuitive gestures and movements and sketch/draw directly on the immersive environment or move the objects to a different location. The intention behind this ability is to create a more intuitive and creative digital application that could involve the user in the design process naturally. Nevertheless, most of these studies involve very simple geometrical shapes or game-like interiors and the tasks usually include connecting walls to create a 3D space on the spot (in this case the finished outcome is often very crude and cannot be used as a final complete model) or to move pieces of furniture from the original to another predetermined position. In addition issues relating to interface, hardware, scale, loss of orientation, etc. have not been entirely resolved yet. The majority of these digital design tools are still under development.

In short, the system in this study was not designed to help students to create their models but to give them a flavour of how the interior would look in real-life size. Furthermore, since we utilised fully completed interiors, the level of the complexity was much higher than what these applications are using. However, if in the future the ability to interact with all the 3D elements of the interior is deemed necessary and important for the design process then this could be integrated by an experienced programmer in 3D applications.

The idea to include **avatars** in VE was also discussed. The argument here is that when students are viewing a VE on a computer monitor, the scale of the graphics is very small compared to the real-size model hence the addition of an avatar in the environment helps them to realise the size of an interior by comparing the height and width of the avatar to the surrounding elements of the space. This type of immersion and interaction with the virtual world resembles video games.

In our case, the 3D models are presented to the students in real-life scale hence an avatar was not deemed suitable. The presence of an avatar would probably obscure the user's view; the viewpoint of the user is usually positioned further behind the avatar and slightly upwards so as to give a better view of the character and the surroundings. Usually immersive applications like this one do not involve avatars as the user theoretically takes that place in the virtual world and experiences the environment through his/her perspective (first-person viewpoint).

Avatars are most commonly used in real-time multi-user or multi-player worlds like Second Life. The purpose of having an avatar in these types of environments is to represent oneself and also to interact with other people's avatars. In this study, each user navigated inside an interior while the others watched the exploration. User interaction within the VE was considered neither fitting nor beneficial for the purpose of this study. Nonetheless, other research efforts have focussed on incorporating designers' avatars within the same virtual space, to aid collaboration between design studios located in different parts of the world. This simulates a virtual site visit where interaction and communication between the different parties is crucial. That system was created to facilitate communication between big architectural companies working on larger projects and not for educational purposes.

8.3 Issues and Limitations

The study highlighted an issue that is important to resolve in the future if the interior design department at GSA decides to implement this technology in the studio regardless of the type of display: **the conversion of the 3D models into VEs**. Many technical problems arose during the exchange of files between programmes, yet I managed to resolve most of the problems by using two or three different modelling software packages and by rebuilding the surfaces that had been corrupted during the conversion. This process took much longer than anticipated, but all the models were ready in time for the trial. Hence this issue did not affect the experiment in any way. It is, nevertheless, a major practical issue that needs to be resolved as this conversion process should be easy and straightforward enough for the students and tutors to execute by themselves without having advanced 3D or programming skills. Therefore, before proceeding to any purchase of equipment it is crucial to identify the best technique to transform the student's 3D models into interactive virtual environments. That is the reason why the investigation for an optimal workflow became a high priority in the follow-up study.

Another problem that this study underlined was that the difference between the two physical rooms that housed the displays introduced a **variable** that had a bigger effect on the outcome than anticipated. A stereo active VR display requires a dedicated room and absolute darkness thus it would not be possible to transfer this setup into the WP room to repeat the experiment. However, the idea to compare the effectiveness of a normal WP (one projector) to the widescreen WP (two projectors) on the same activity emerged. The suggestion was to explore whether a smaller size display surface, thus a cheaper system, could have the same impact on this learning task.

Basically, given that the study presented in this chapter provided positive results with regards to the use of VEs in interior design, the tutors and the head of the department were keen to implement the technology in the studio, so another round of trials was necessary in order to determine which software and hardware the department should purchase. In essence, the issues and the limitations that this trial encountered informed the design of the follow-up study presented below.

9. Follow-up Study

The follow-up study took place in 2007-2008 almost a year after the initial study. The positive feedback received from the students about the effectiveness of the displays as a design review tool encouraged both departments involved (DDS and Interior Design) to submit an application to an internal / institutional Learning and Teaching Innovation Fund in order to fund a follow-up series of trials to test different display configurations with a wider variety of 3D models. The research application proposed to conduct a feasibility study on how to introduce an immersive VE into the interior design studio space. It basically aimed to examine the procedures required to integrate such a system into the department's workflow.

The application was successful and a team of four people with different expertise was formed between the two departments[35].

9.1 Aims and Objectives

We recognised that the success of such a system depends greatly upon the ability of staff and students to use it easily in their day-to-day working environment, to view and evaluate the projects in full scale as part of the design process, thus an optimal workflow had to be set. A second and equally important issue for the implementation of this technology in the studio was the cost of software and hardware required. Taking both these matters into account, we opted for open source software, where possible, and off-the-shelf technological equipment.

The aims of this study were again twofold. First, our intent was to identify the workflow procedure together with the technical infrastructure which would allow students and staff to transfer models easily from their CAD software into the VR authoring software. Second, we conducted a trial with seven 2nd year and seven 3rd year interior design students in order to evaluate three different immersive display configurations: a widescreen WP (4.4x1.65m), a normal size WP (2.2.x1.65m) and a 3D passive stereo projection (2.2.x1.65m). Note that at the time the preliminary trial took place the passive stereo projection was not available. In addition, since the previous study showed that the active stereo VR display may not be suitable for the design review task it was not included in this comparative study. The students were given the opportunity, using the three displays, to review six different interior designs as they would do during a crit session in their studio. The evaluation measures applied here involved structured and open-ended questionnaires, observations and group discussions.

The lessons learned from this project were expected to have immediate practical benefits for the department of interior design, inform the development of educational technology in Art and Design and lay a foundation for wider application to other departments across the institution i.e. Architecture.

9.2 Identifying an Optimal Workflow

The first stage of this research was to specify an efficient pipeline for converting the 3D models to be used in the test. Therefore, prior to the actual trial, we tested various applications so as to determine which one was more suitable in terms of cost and

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[35] One tutor from the interior design department, who is also responsible for teaching the 2D and 3D software packages; a researcher who has experience in conducting user tests with designers and 3D technology; a research programmer who is specialised in 3D and VR applications and also has experience in user testing; and myself.

compatibility with the 3D software package the department uses (VectorWorks). For financial reasons we opted for an open source VR software, the OpenSceneGraph[36] in particular.

After numerous attempts with various file formats and settings, we concluded that in order to achieve better results in transferring models from VectorWorks to the VR software OpenSceneGraph it was necessary to introduce a third application that serves as the intermediate link. For this purpose we chose Right Hemisphere's Deep Exploration 5.5 Standard Edition[37]. Nevertheless, the conversion process still requires some actions to be performed in VectorWorks to ensure a smooth transfer of the models into the VR software.

Apart from the educational impact, the other reasons for contrasting these three displays were related to cost-efficiency and feasibility issues. In particular, the normal WP is a simple wall projection using one projector, which is the most typical setup for presentations and can be found in most classes, seminar rooms, etc. The widescreen WP uses two projectors hence the display area is almost twice as wide. On the other hand, the passive stereo VR display covers the same surface as the normal projection yet it offers the depth perception effect through the use of two projectors, special filters, screen material and 3D polarised glasses (the two projectors' images are overlapped to create the 3D effect). Furthermore, while the previous study used two different physical rooms, the current trial was conducted in the same physical space thus providing better control over the experiment and less variables.

9.3 Participants

Two groups of interior design students were chosen to participate in the tests: seven 2nd year students and seven 3rd year students. We decided to work with two smaller groups rather than the entire 2nd and 3rd year groups. Seven students from each year group, who represented a range of computer and design ability, were recruited. In addition we decided to work with one year group at a time. The 3rd year students had experience of using similar display systems since they participated in the first study while the new 2nd year class had never used this type of system before.

The tutor, who was also a researcher in this study, participated in the trial by conducting the design review session as he would normally do in the studio. The other three researchers were present in the room during the sessions and observed the process, while they also raised questions when appropriate in order to record the students' views. During the group discussion, mainly the tutor raised the questions, but the other researchers often asked the students to further clarify or explain their views.

[36] The OpenSceneGraph is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling.(http://www.openscenegraph.org)

[37] http://www.righthemisphere.com/products/dexp/de_std.html

9.4 3D Models

Six different designs, from three project types (*Cube House, Music Office, Dentist's Office*), were used for the tests. Each had different characteristics, allowing a variety of design issues to be explored and examined within the display configurations. Two designs were reviewed in each configuration, so that issues of design were not conflated with those of display type.

9.5 Design of the Study

Between groups, different designs were used within display types, again so that issues of design were not conflated with those of display type. At the beginning of each 'new' display type, a practice model was used to allow the students to familiarise themselves with navigating in the new configuration. We deliberately chose models that did not belong to any of the students in the group, although the third year student group had previously seen one of the designs, as it was from their own year group's previous year's work.

Table 6.2: Test configuration.
[Note: 1 = k-cube, 2 = j-music, 3 = m-cube, 4 = s-dentist, 5 = d-cube, 6 = z-music]

2nd year students					3rd year students			
Model	Normal	WP	Stereo		Model	Normal	WP	Stereo
Test	√				Test	√		
1	√				1	√		
2	√				2	√		
Test		√			Test			√
3		√			3			√
4		√			4			√
Test			√		Test		√	
5			√		5		√	
6			√		6		√	

The three display configurations were situated in the same physical environment: a meeting room with the display at one end and a large table at the other. The same interface (joystick and navigation software) was used in each display environment to navigate through the model. Other than the display configuration itself, the main difference was that in the passive stereo configuration the students had to wear glasses with polarising filters to view the designs in 3D. The order of display types was changed between groups to minimise as much as possible effects of familiarity influencing preference (Table 6.2).

It must be stressed that these tests were not designed to be exhaustive; rather, a pragmatic approach was taken in which we aimed to address major potential effects (such as order of display affecting preferences, and conflating design issues with those of display configuration), within the constraints of the time and participants available. The aim was to determine whether or not there were clear advantages to one display type over another, in the practical environment of a crit session.

9.6 The Study

At the beginning of the test session, the participants were given an introduction in which the purpose and conduct of the study was explained, and consent obtained from the participants. The test was split into three review sessions, one for each display configuration (see Table 6.2). Once each of the students had familiarised themselves with navigating in the new configuration using a test model, two designs were reviewed. We explained to the participants before starting the reviews that they would be asked to evaluate the strengths and weaknesses of each design. An hour was allowed for each of the review sessions, with breaks timed to coincide with changes in display. Once the review sessions were complete, a group discussion concluded the day.

The focus of the discussions during the review session for each model was on the designs rather than the technology (although comments on this aspect were not discouraged). We anticipated that this would allow issues about the impact of the technology on the design review process to emerge naturally, as well as through the more technology-focused aspects of the end-of-day discussion. For each design review issues such as the practical, functional aspects of the design, its compliance with the brief were discussed as well as more aesthetic and 'feeling' related aspects such as e.g. *'Does it convey the right atmosphere?'*, '*Does it conform to the 'back story'*?'. A number of topics was intended to be covered during the discussions (although items in italics were only raised with 3rd year students, as the 2nd year students may not yet have the experience to discuss these issues): atmosphere, practicality / function, appropriateness of size, *construction, materials*.

At the beginning of each review session (new display configuration), the participants were all encouraged to familiarise themselves with navigating in this new configuration using the practice model. The participants, led by the tutor, then reviewed two interior design models of different types within this display environment. Only one participant could navigate at a time, using the joystick. There was no strict rotation of navigation between participants; rather people were encouraged to take the opportunity if / when they wished.

As well as the computer models, the tutor had brought plans for each of the designs under review in case participants needed to refer to them. During the progress of the tests, the tutor introduced the idea of asking the students to draw a rough plan of what they thought the model looked like by only having explored it though the VR environment. Then the group compared their drawings with the printed plan; this was not something we had planned to do, but emerged during the tests as a useful exercise. For this reason, it is not incorporated in the analysis, but would be a useful instrument in future studies.

After reviewing two designs, the participants were asked to complete a brief questionnaire by listing the three things they thought were strongest about each design, and the three things they thought were weakest about each design; this was to assist in focusing their thoughts on design issues, to give us an idea of the things they have noticed and engaged with in each design (in each configuration), and to act as a prompt for the group discussion at the end of the day.

Once all three review sessions concluded, the participants were asked to complete a questionnaire focusing on comparisons between the different display configurations (see Appendix 3). First they were asked to rate each configuration using 5-point scales on issues including sense of scale, comfort, ease of navigation, and sense of immersion; these were all issues that had emerged as important in the previous study. Next, they were asked to indicate which display configuration they preferred (choice), and why (open answer). Finally, they were asked, for each display configuration, to write down (a) what, for them, were the main benefits and drawbacks of each type of display, and (b) how important they thought these benefits / drawbacks were in this type of review activity.

This final question was aimed at establishing not just what they found good and bad about the displays, but what they felt the relative importance of these characteristics might be i.e. to make them think a little more deeply on what the practical implications would be if they were using the system in earnest. For example, something might seem to be a big drawback, but if it would only happen very occasionally in regular use then that is different to if it occurred more frequently. On the other hand, something might initially seem as a small drawback, but it could actually cause annoyance every time that the system is being used. The question was deliberately left non-specific to allow the students to identify a range of possible benefits and drawbacks, including ones which we had not anticipated. It was included in the questionnaire to allow / encourage them to talk about things that we had not specified in questions 1-4, and to get each of their ideas down, before group dynamics took over in the group discussion.

9.7 Group Discussion

We had prepared a list of topics (not to be strictly followed) which we wished to cover in the discussion (as well as allowing issues to emerge from the day's activities), relating to the use of this type of technology in review sessions, and students' views of its potential within the studio:

- did the technology help to create a better review process?
- would you like this technology within the studio?

- how do you imagine that you may use this technology within the studio?
- shared experience
- is there a difference between navigating and watching?
- do textures and colours help or detract?
- how useful is the ability to go outside the model?

In addition to the questionnaires, the review sessions and group discussions were video and audio recorded. This was to allow the identification of issues around:

- people's behaviour e.g. how they used the joystick, where they sat / stood / moved around
- group interaction, particularly in relation to navigating with the single joystick
- comparisons between things that people do and what they say (particularly if there are any conflicts between the two)
- issues that emerge as important that are not covered in the questionnaire, and / or that we did not anticipate
- where the display and interaction system began to cause problems, or let the participants do things they couldn't do otherwise

9.8 Outcomes

This section provides a summary of the main findings of the follow-up trial as derived from a preliminary inspection of the data. The students' responses and some quantitative data are offered in Appendix 4; however, the analysis of the data has not been included in this thesis given that the main findings were similar to the previous study described in detail in this chapter.

From the initial discussions with the students it was concluded that each display type was useful for different activities, rather than one preferred overall. For instance, the passive stereo 3D provided a crisp image and the best perception of depth and distance, but was perceived as more suitable for individual exploration of designs, or for one-to-one tutorials. The normal WP, on the other hand, was considered good for group discussions. The option to use the second projector to simultaneously project other representations (plans, high quality renderings) next to the VE was proposed. The students felt that the widescreen WP slightly distorted the geometry, especially at the end sides of the display. Furthermore, they thought that the scale of the models as seen on the widescreen WP was not as representative of the actual scale as on the other two displays (normal WP and stereo 3D). There was no clear agreement between the students as to which display was preferable. However, all students agreed that the ability to move inside the 3D models, in almost actual scale in all three displays, was very beneficial and that they cannot experience this through the other visualisation methods.

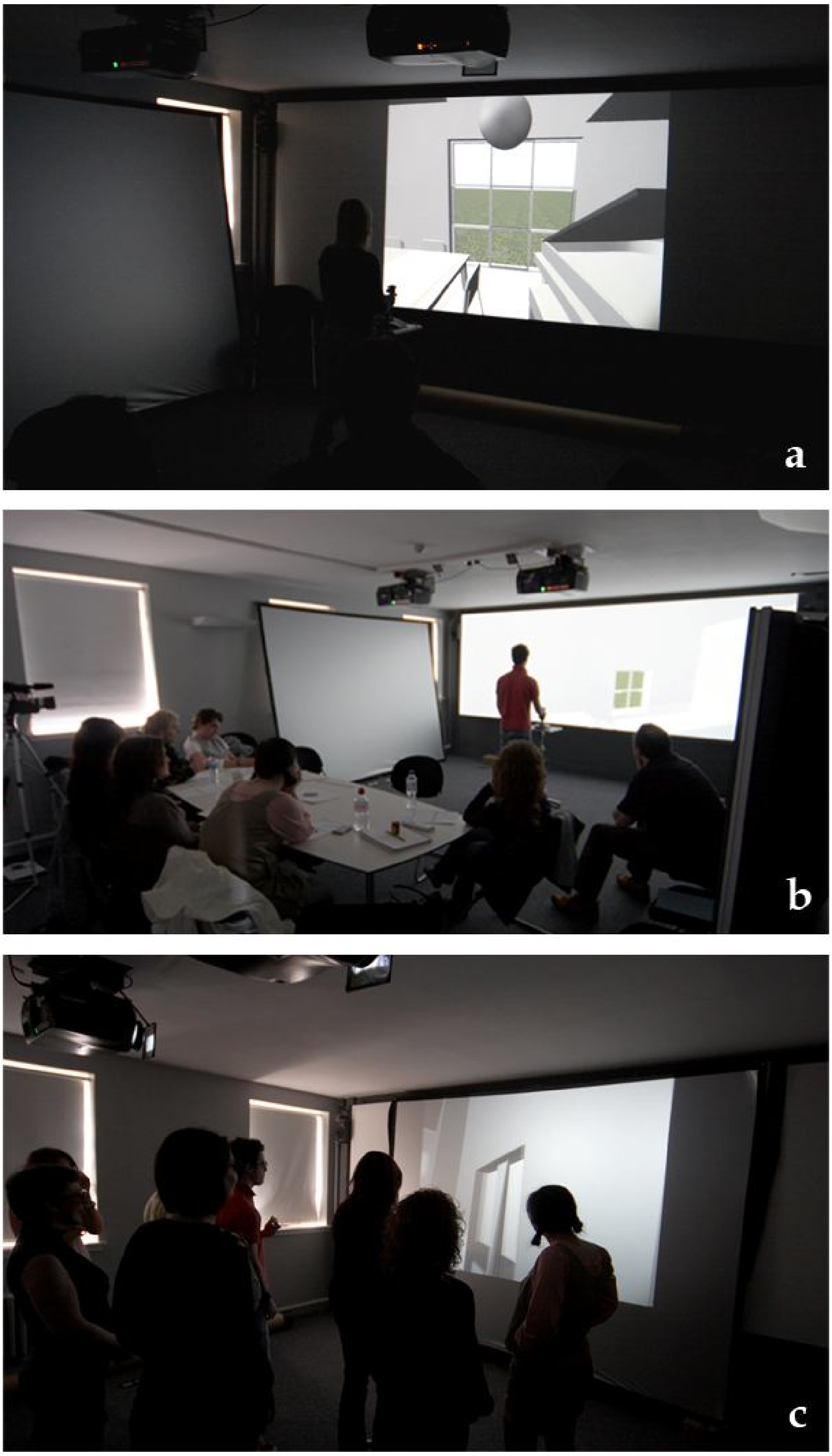


Figure 6.9: Photos taken during the trials: (a) normal size WP (b) widescreen WP and (c) 3D Passive stereo projection.

In a nutshell, this feasibility study aimed at identifying, broadly, whether there were any clear advantages of using one display configuration over another in a studio review setting. It produced a working methodology and recommendations for best practice in using a spatially immersive VE within normal studio practice along with a specification for the technical/hardware infrastructure (projectors, computer, 3D glasses, polarised filters, navigation device and software) and physical environment (blinds, screen) required (Appendix 5). Note that the problem of having to introduce an intermediate software package to import the 3D models created in VectorWorks into the VR application software (OpenSceneGraph) was resolved after the trial by the 3D programmer who developed the DesignViewer (the software description and code are provided in Appendix 6). This software facilitates the conversion process by allowing the 3D models to be directly imported and optimised in OpenSceneGraph without having to go through another software package (it also generates shadows). This eventually reduces the expenses for software since there is no need to purchase additional software and OpenSceneGraph is an open-source application, and eases the conversion process.

What emerged clearly from the tests, even before a detailed analysis of the data, was that the preferred solution was likely to be a flexible two-projector configuration which would allow for all three display types to be used, as even the basic ‘normal’ WP system could provide significant and immediate benefits to the students and staff.

Furthermore, as a result of both the preliminary and the follow-up study, the interior design department decided to purchase the hardware and software in order to install a flexible two-projector approach. Note that the layout of the interior design studio had undergone changes during the summer holidays in order to create space to accommodate the display. At the time this thesis was written, the equipment was just being purchased and installed within the studio therefore there were no reports yet on how the staff and students were utilising the display. Additional issues could be identified either through further analysis of the data collected (including the design crit sheets), or through more fine-grained testing once a system is in place within the studio.

10. Conclusions

This chapter presented a study that evaluated the use of VE and compared the impact of two different spatially immersive displays on cultivating interior design students’ spatial understanding. This experiment showed that an immersive VE can be beneficial for studying, reviewing and assessing the learner’s designs. Nevertheless, the successful use of such technologies depends on the design of the learning activity (content and context). The promising outcomes that this trial produced may not be transferable to all the educational tasks that interior design students have to perform. For example, this VE, and I am referring only to the VE used in this study, is not appropriate for studying metric distances between structural objects, but it is helpful in terms of offering a sense of scale and proportions. The representation of the actual scale is probably not precise either but the spatial relationships within an interior can be conveyed successfully. Furthermore, it is not so effective for simulating realistic light conditions, shadows, reflections, refractions, radiosity and so on. Therefore, recognising the limitations of these systems is a first step towards a more successful employment of them as they should be utilised according to what they can offer and not what is expected of them. This study proved that this system can resolve one of the educational problems this discipline has been encountering for many years.

In brief, the study has certain limitations, yet it provides a foundation for subsequent investigations. The findings are applicable to similar learning activities and to related disciplines and can be used as a point of reference for further research. Another valuable outcome of this study was that it produced a working methodology and recommendations for a cost-efficient solution in setting up and using a spatially immersive VE. These could be used by other researchers and tutors who wish to install a similar system in their teaching studios.

As a result of the positive outcomes of the follow-up study, the interior design department at the GSA received funding to purchase the equipment to set up a spatially immersive display within the studio space. The layout of the studio was altered in order to accommodate the display, but this is also expected to create better review / crit sessions. Once the system is set up then further studies could be conducted to evaluate the impact of the long term use of the technology on interior design education.

Chapter 7

Conclusions

This thesis has examined the application of 3D visualisation technology in Art and Design education. In particular, through the three empirical studies presented here, it set out to provide definitive examples of educational benefit in integrating appropriate forms of 3D visualisation technology into current studio-based learning environments. The secondary research showed that the educational topics chosen for this investigation have been encountering problems in their delivery. These issues could be partly or fully resolved with the aid of systems that provide a more interactive, three-dimensional and immersive experience to the learners. In essence, this research proposed and designed three learning activities for these topics using a learning event-centred approach and evaluated the learning and teaching experience using primarily qualitative research methods.

This investigation has been situated within the context of introducing 3D visualisation technology for learning and teaching purposes in the domain of Art and Design and not for designing and creating artefacts. This work proposed the use of readily available 3D visualisation systems to aid and enhance current learning and teaching in the discipline. Taking into account the recent changes in art schools that have been discussed in previous chapters (e.g. increase in student numbers, introduction of new subject areas, the need for more updated content and context, the trend for learner-centred education, etc.), this study set out to suggest solutions to educational problems by examining the potential of using affordable and user-friendly 3D virtual environments.

The technology presented here (desktop 3D virtual environments, VR, immersive displays), has been used in other disciplines for many years providing some favourable results in terms of educational impact and motivation for the learners. However, in Art and Design, only a few examples of the use of this technology for learning and teaching can be found in the literature. There are even fewer publications that report on any evaluation outcomes. The idea to use this technology to explicate concepts and present design ideas more effectively is not new, but in the field of Art and Design, such ideas have not been properly exploited. This research tested a variety of 3D virtual environments, from desktop-based learning environments to spatially immersive displays and from a VR system to a simple wall projector. Apart from offering a theoretical basis and empirical evidence on how some Art and Design courses could benefit from the employment of such technology, this thesis also offers paradigms of how to incorporate different types of 3D technology in the teaching studio environment. The third study, in particular, examined the feasibility, in terms of space and cost, of setting up a spatially immersive environment in an interior design studio.

In brief, this thesis examined the implementation of 3D visualisation technology in Art and Design education through empirical studies of three innovative educational designs. The previous chapters have described the motivation behind this investigation, introduced the different elements of the research, presented the empirical work and discussed the findings. This final chapter places the research within a broader context. It summarises the main findings, reflects on the effectiveness of the research methods used and discusses the limitations of this investigation. It then outlines the contributions of this research for Art and Design education and proposes avenues for further investigation.

1. Summary of the Main Findings

The findings of each study have been discussed at the end of the corresponding chapters. This section provides a summary of the findings that have implication for Art and Design education in general and not only for the particular educational topics examined in the studies.

- The findings of the three studies showed that in those instances the use of 3D visualisation technology gave the participants a better and deeper understanding of the concepts, ideas or designs under investigation.
- The 3D virtual environment provided another perspective on the concepts that the existing learning and teaching methods did not convey successfully. At a minimum when the topic under investigation is inherently three-dimensional, it is worthwhile to show the third dimension to the learners as it helps to make the concepts and the designs easier to understand.
- Studies 2 and 3 demonstrated that the use of a spatially immersive display resulted in more efficient and productive review and crit sessions. The technology gave the participants a shared immersive experience of the designs, which naturally created the conditions for discussions among learners and between learners and tutors to take place. It seems that immersion inside the designs not only gave the students a better understanding of the spatial attributes but also gave them confidence and control over the presentation of their designs during the review session. In addition the tutor also thought that the review process could be carried out more successfully with the help of this technology as it reduces the occurrences of misunderstandings since the designs are presented in real scale. Therefore, the review sessions became more constructive for the students as they had the opportunity to see each others' designs and participate in the discussion.
- The research also highlighted the importance of a carefully designed learning activity that accompanies the implementation of the technology. The technology cannot be used as a learning and teaching medium on its own for it requires the incorporation of a suitable educational framework. The learning activities for all three studies were based on educational theories which were identified as appropriate for the particular discipline and topic under examination. Furthermore, the technology needs to be applied in a manner that is sympathetic and non-intrusive to existing practice in the teaching of Art and Design and that it is designed to cater for the needs of a particular audience. If it does not share the same ethos, or fit the studio-based learning approach, it might not be considered part of the same discipline, and could eventually lead tutors and students to discontinue its use.
- The technology can be introduced without the need to change the existing teaching philosophy and practice. The key here is to find ways to adapt the technology to the needs of Art and Design education. Many tutors have been sceptical about introducing technology in the studio environment as they feared that everything had to change, not only physically, such as moving from a drawing board to a computer screen, but also

that changes would occur in the educational philosophy. As the three studies demonstrated, tutors actually benefited from the use of 3D technology as it made their work somewhat easier by resolving issues they have been encountering for many years. It is important for educators to feel comfortable using technology and to be in control of it; to consider it as supportive and not as a tool that could replace them.

- 3D visualisation technology, as implemented in the three studies, aided the teaching of the topics. For instance, in the Colour Theory study, if students had access to a fully functional software implementation of the learning design, this would imply that teaching hours could be reduced as the students could study Colour Theory concepts in their own time, at their own pace and place. In a similar vein, in Studies 2 and 3, the technology made assessment of the designs easier and more productive for both the tutor and the students.
- The studies also showed that a combination of different teaching techniques and visuals is beneficial for achieving a better understanding of concepts and designs. To reiterate, the purpose of introducing the 3D technology in the particular subject areas chosen was to enhance current learning and teaching and not to substitute the tutors.

2. Effectiveness of the Research Method

The research methods applied in this research are commonly used in educational technology studies. Apart from the secondary research methods, which involved a literature and contextual review on Art and Design education as well as 3D and educational technology, this research used primarily open-ended measures in forms of questionnaires, interviews, observations, group discussions, etc.

The strategy followed for each of the three applications was presented in Chapter 1. To reiterate, the first stage was to identify the educational problem and interpret it using educational theory. Then a solution was proposed and a learning activity was designed based on 3D visualisation technology. The learning activity and the technology were evaluated through learner trials using mainly qualitative methods.

This research followed a learner / tutor-centred rather than technology-centred approach. A number of educational technology studies give more emphasis on the evaluation of the individual features of the technology rather than the learning outcomes, whereas this investigation's aim was to gauge the learning experience by capturing the participants' views, feedback and suggestions. It was essential to take into account the students' and tutors' views in this matter since they are the potential end users of such systems. For the technology to be successfully introduced in the studio and to be used on a daily basis by both students and tutors, it needs to meet their requirements and their needs without adding extra difficulties and obstacles.

The open-ended measures applied in the three studies allowed for unexpected findings to arise. This was an advantage as often I might not have given enough emphasis on an issue which turned out to be important for the students. On the other hand, a more structured quantitative method might have provided clearer numerical results regarding the educational effectiveness of the systems. However, I was concerned that this might not render an honest image of the situation. When possible, both quantitative and qualitative techniques were applied, as in Study 1. However, the nature of the topics of Studies 2 and 3 were not suitable for quantitative measurement of the learning outcomes. This is partly because assessment in Art and Design education is not normally carried out by providing answers to multiple choice questionnaires. Students are assessed on their finished project and are evaluated on factors such as creativity, innovation, progress, participation, collaboration, etc. Therefore, it would not have been appropriate to apply an assessment method that is not in line with the current ethos of the discipline, and which staff and students are not familiar with.

In short, the methods applied in this investigation were successful in terms of providing answers and insights to the questions posed at the beginning of this research. The methods also allowed for interpretations and ideas to arise that might have not been initially the focus of this research. Moreover, these methods have been applied by most studies in the area of Art and Design, and educational technology.

3. Limitations

Although the research met its objectives and the findings evidently addressed the research questions that had been set at the beginning of this investigation, certain issues and limitations affected and modified the course of this research.

One of the limitations of this research was that it did not examine the effects of the implementation of the technology after long term use. All three studies were short term, offering the participants only one or two exposures to the technology. Reflecting back on the first study, my idea to develop a 3D learning application for teaching Colour Theory concepts was probably too ambitious since for the reasons explained in section 8.3 of Chapter 4, this could not have been realised only by one researcher. Although the theoretical framework for the application was in place, the development of the fully functional application required funding and collaboration with 3D programmers, which was not feasible in this doctoral study.

Therefore, I decided to explore more topics. In the long run, this decision had more benefits than drawbacks. First, it naturally led the investigation into other areas where persisting and ongoing issues could be resolved with the aid of 3D technology e.g. the problem of visualising the interior designs in real-life scale. Second, by investigating three cases, the research covered more areas of Art and Design which also allowed me to test a range of different 3D visualisation systems which again offers a wider variety of examples with regards to which type of display or system could be suitable for one topic but probably not appropriate for another. Although the investigation of more topics could have provided this research with more evidence on the use of this type of technology in Art and Design, this was not fulfilled for reasons related to time, cost and technical knowledge needed to carry out more studies. In any case, I believe the findings of the three studies established clearly the educational potential of the technology.

With regards to Studies 2 and 3, the investigation might have been more efficient and easier to control if I had been a member of the interior design department (e.g. either a tutor or a former student). A higher level of familiarity with the students and being able to have constant access to the studio to observe daily tasks being carried out would have made this investigation easier. It has to be stressed, however, that the interior design staff were very helpful and had encouraged me to visit as often as necessary. Being a visitor did not give me the right to interfere with the daily schedule or the tasks given to the students and therefore I had to depend on and work closely with the staff to conduct the trials at a time that suited them. Furthermore, being familiar with the students and their work could probably allow me to detect potential shifts in their design workflow, in the way they used the 3D software, the way they perceived spatial arrangements, etc. Nonetheless, this issue did not have any major impact on the findings although it could have made the process easier and probably added some additional insight.

However, the above issues could be overcome in future research. For instance, once a system is set up in the studio, its long term use could be evaluated directly by the teaching staff of the interior design department thus resolving the familiarity problem. This will be discussed further in the future research section.

An issue, which is probably not a limitation but nevertheless I considered to be one of the difficulties of this research, was the lack of literature and studies in this field. On the one hand this can be seen as positive, as the area is fairly new and unexplored hence ideas can still be innovative and new. On the other hand, the paucity of prior research makes new research harder as there are not many similar studies to compare the results with in order to back up arguments. While for the first two studies there was very little research on the use of 3D technology for learning and teaching in the particular areas, for Study 3, due to a number of studies conducted in Architecture, I was able to compare and confirm my findings. This is not exactly a limitation of this study but it definitely shows that educational technology research in Art and Design is an area that has not been given appropriate attention.

4. Contributions of the Research

- The research findings demonstrate that 3D visualisation technology, in its various forms, can resolve some educational problems that are commonly encountered in Art and Design.
- The literature review identified that the delivery of some educational topics can be problematic as existing teaching techniques based on traditional visualisation methods might not be adequate for grasping concepts or understanding the nature of a 3D design.
- The research reviewed the current state of Colour Education, outlined the problems, and proposed solutions on how Colour Theory courses could become more effective.
- The study has implications for both Art and Design and Architecture. Since interior design and architecture are related areas, the examples raised in this thesis could be easily applied in other areas of the built environment.
- This study provides suggestions supported by evidence with regards to the effectiveness and suitability of the various 3D visualisation systems for different educational topics. The research, apart from proposing a theoretical framework for implementing the different types of 3D technology, also designed and evaluated three learning activities. The three case studies can be used as examples or suggestions on how to introduce the specific types of technology in Art and Design education. There are a number of institutions that already own this sort of 3D system but probably have not utilised them for teaching before, as they are mostly used for presentation purposes. Similarly, other institutions might have the intention of updating their learning environments by purchasing new systems but may not know what is suitable.
- This research hopes to encourage and inspire Art and Design educators to introduce 3D visualisation technology in their teaching, where and when it is deemed suitable and necessary. The technology has some advantages to offer as proved in the case studies therefore these could be exploited to create improved learning environments. Tutors should not be afraid to adopt the technology, use it, customise it, improve it and tailor it to the needs of their courses and experiment with it. In addition, this research could give ideas to educators on how they could use simple existing 3D technology in their programmes of study. As demonstrated, even a simple wall projector could be used to

create an immersive environment while the interface from 3D software can be used to present a 3D colour system and carry out a problem solving exercise. It is about using the equipment in an innovative way.

- The research produced guidelines on how to set up an immersive 3D virtual environment in any studio space by listing both software and hardware specifications.
- It contributed to the existing literature on educational technology by introducing evaluation studies carried out in the field of Art and Design. The number of published materials related to technology in Art and Design education is very limited compared to the amount of studies dealing with science topics. There are two explanations for this: first this area is still fairly new and unexplored and second, conducting formal user studies and publishing the results in academic journals has not been common practice in Art and Design.
- This research proved once again that cross-discipline collaboration is important and advantageous. Art and Design can benefit from developments in computer science as well as educational studies. They might seem as worlds apart but there is some common ground and each side could benefit from such collaboration.
- This investigation attempted to provide realistic and cost-efficient solutions to the identified problems. Art and Design institutions do not usually have the same budget or technical support as universities therefore cost is always considered when making decisions about purchasing new technology, hence, this was important to address. With this in mind, the research sought and suggested realistic and economically viable solutions.
- As a consequence of this research, the interior design department at Glasgow School of Art, after conducting the third and the follow-up study, received funding to install a spatially immersive display in the studio. As this thesis was completed, the department was in the process of installing the equipment and testing out the VR application software. This was for me the biggest reward: to witness part of this research becoming real by putting the theoretical concept into practice.

5. Future research

Although the research has certain limitations, it has provided a foundation from which to proceed and its findings could serve as a stepping-stone for subsequent inquiries. Through the course of this research and upon reflection on the findings, several prospects for future work became evident and some of the issues I encountered may become the subject of further study. These are summarised below.

An area of enquiry that could rationally be pursued as a result of this research is the development of a learning application for Colour Theory. Study 1 created and evaluated the concept behind the learning activity hence a software developer could build on this framework and findings in order to create a final learning product: an interactive 3D application for learning and teaching colour theory concepts. This thesis identified a need for such an application.

As the immersive virtual environment is being set up in the interior design department of Glasgow School of Art, an initial suggestion for a follow-up study would be for the tutors to observe and record its use throughout the academic year. This will offer the opportunity to evaluate the daily use of the technology during a lengthier period of time, something that was not feasible previously. This research may well provide valuable data for the effectiveness of the system in interior design education since the technology will be evaluated inside the actual educational setting and not through artificial user trials. Additionally, a comparison between a group of students that uses the technology and a control group would probably provide further information about the impact of the immersive system. This future study could possibly provide an answer to the following questions:

Does the system improve novice designers' spatial design ability?
Does it make them rely on the technology too much?
Does it foster or hinder creativity?
Do all students benefit from the system? If not, why and how can this issue be addressed?
Does it facilitate the work of the educators?
What are the benefits from its long term usage?

The investigation could be further expanded by evaluating the educational potential of the technology on other topics of Art and Design. For example, fine art is an area that could benefit from an immersive environment as students could study the impact of various fine art exhibitions in real-life scale. However, specific suggestions would depend upon first investigating the issues involved in learning and teaching in this area. The philosophy followed by this thesis was to attempt to resolve problems by using the technology. It does not support the view that technology is the solution to every problem hence a more in-depth analysis of the subject matter needs to be carried out before suggesting and introducing any type of system.

In conclusion, the development of three successful implementations of 3D visualisation technology in Art and Design education established that learning and teaching in this discipline can be enhanced through the application of such technology. This evidence-based conclusion is in contrast to previous such attempts which have typically introduced either generic educational technology, such as commercially available VLEs, without any insight into how these could be relevant in this area of learning and teaching, or else VR technology with attention mostly to technical rather than educational features. This research therefore appears to be one clear example of effective application of such technology in this discipline, and indicates how further such benefits might be achieved.

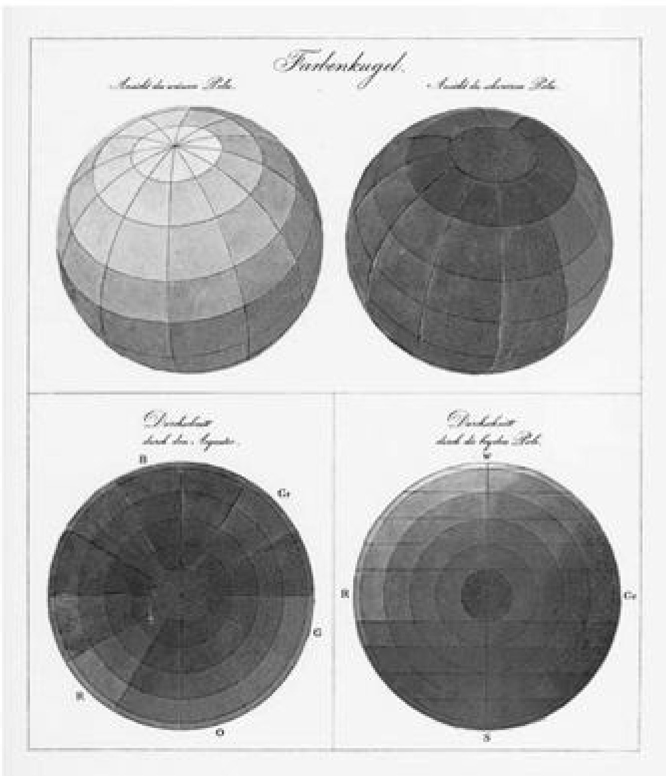
Appendix A

The passage below describes Runge's Colour Sphere. This was given to the participants (text version group) in Study 1 presented in Chapter 4.

Runge Colour Sphere

The spatial representations of the position of colours in relation to each other make it possible to indicate progressive passages of one colour to another with a minimum of ambiguity. Unlike the colour circle which presents only pure colours (hues), the colour solid can be used to plot variations of colour, commonly known as tints (lightened with white), shades (darkened with black), and tones (greyed colours). The breakthrough in system design was the analysis of colour according to three parameters: hue (determined, in pigments, by mixtures of red, yellow, and blue); value (or brightness, showing the amount of white or black in a colour); and saturation (the strength or purity of a colour). These three variables made it necessary to project a diagram of colour in three dimensions-a colour solid.

In the same year that Goethe published his 'Zur Farbenlehre', the German painter Philipp Otto Runge (1977-1810) published 'Die Farbenkugel' (the colour sphere) – the first attempt at a three-dimensional model of colour. Runge presented colour relationships as a sphere (see diagram). Runge's primaries were still red, yellow, and blue, and the remaining nine hues were interspersed to form a diameter or equator around the centre of the sphere. Through the central axis was a grey value scale, from black at the bottom to white at the top. Across the surface of the sphere, the colours were graded from black to the pure hue to white, in seven steps. Intermediate mixtures theoretically lay inside the sphere. The sphere is the elementary shape of universal symmetry. It serves to visualize the rule of complementaries, illustrates all fundamental relationships among colours, and between chromatic colours and black and white. If we imagine the colour sphere to be a transparent body, each point within which corresponds to a particular value, then all conceivable colours have a place.



6.7 **Philipp Otto Runge, Color sphere from *Die Farbenkugel*, Hamburg, 1810**

The prompts:

1. Why does colour X go in position Y and not position Z?
2. Before with these same cards you organised them like A and now you have them organised like B, why is that?
3. Why have you done it like that?
4. Why is colour X at the end of the line? Does it make any difference which colour is at the end of the line?
5. Can you think of any other way to arrange them which might solve that?
6. If I gave you these additional colours, how would you arrange them now?
7. If I take these colours away, do you now concede that all the colours are related in some manner, if there were a sufficient number of intermediary colours?
8. Other / Not a pre-defined prompt

Question addressed to the material-version participants after arranging the cards:

Q. Given that you have been arranging the cards, and all the arrangements you have already put the cards in, with these in mind, if I gave you this model can you think of any way in which the colours could be arranged on it, that might resolve some of the problems you have found whilst trying to arrange the cards on the flat?

Question addressed to the text-version participants:

Q. Here is a model sphere. Having read the description of Runge's Colour Theory can you think of how colours could be arranged on it, so that they depict the model of colour that was described?

Test Questions:

1. What colour goes here? (half way between green and black)
2. What colour goes here? (half way between red and grey)
3. Describe what the colour at this point would appear like? (from colour swatch)
4. Where would brown fit in this model?
5. What is good about this model?
   - Contains all colours
   - Shows relationship between colours
6. Would a cylinder or a double cone serve the same purpose? What are the strengths and weaknesses of the sphere shape?
7. On a scale of -5 to 5 how much have you enjoyed this task?

Various arrangements of the coloured tiles both material and digital.

Appendix B

Consent form and information sheet given to the interior design studies at the first stage of Study 2:

Information Sheet

This study is part of a Doctoral research that investigates the use of 3D visualisation in art and design education.

Participation in the study is voluntary, and should you wish to withdraw participation at any point you may do so without having to provide a reason. All data collected from you will be treated with full confidentiality as they will be coded in such a way that your identity will not be identifiable as your own. The results of this research may be published but your name will not be associated in any way with the findings.

As a part of a competitive biding contest you are asked to propose a colour scheme for this general use public room situated within a larger office complex.

Create a colour scheme for this 3D interior by selecting 5 colours from the provided Palette (Page 2). You will have to select 3 of the colours from the same row (e.g. G1, G2, G3 or Y1, Y2, Y3) and any other 2 colours. Two perspective views of the floor plan can be found on Page 3. You will be given an hour to study the floor plan and write down the codes of the colours you wish to apply on each surface (You can also write a note of these on to the 3D views sheet). Please provide your details and answers on the back of Page 3.

The forms will be then collected and you will be called to work on your design with the researcher on the 3D software.

A visit to the Digital Design Studio will be arranged in the following weeks where you will be able to experience your design in Virtual Reality.

If you require further information about this study please do not hesitate to contact me.

Thank you for your time.

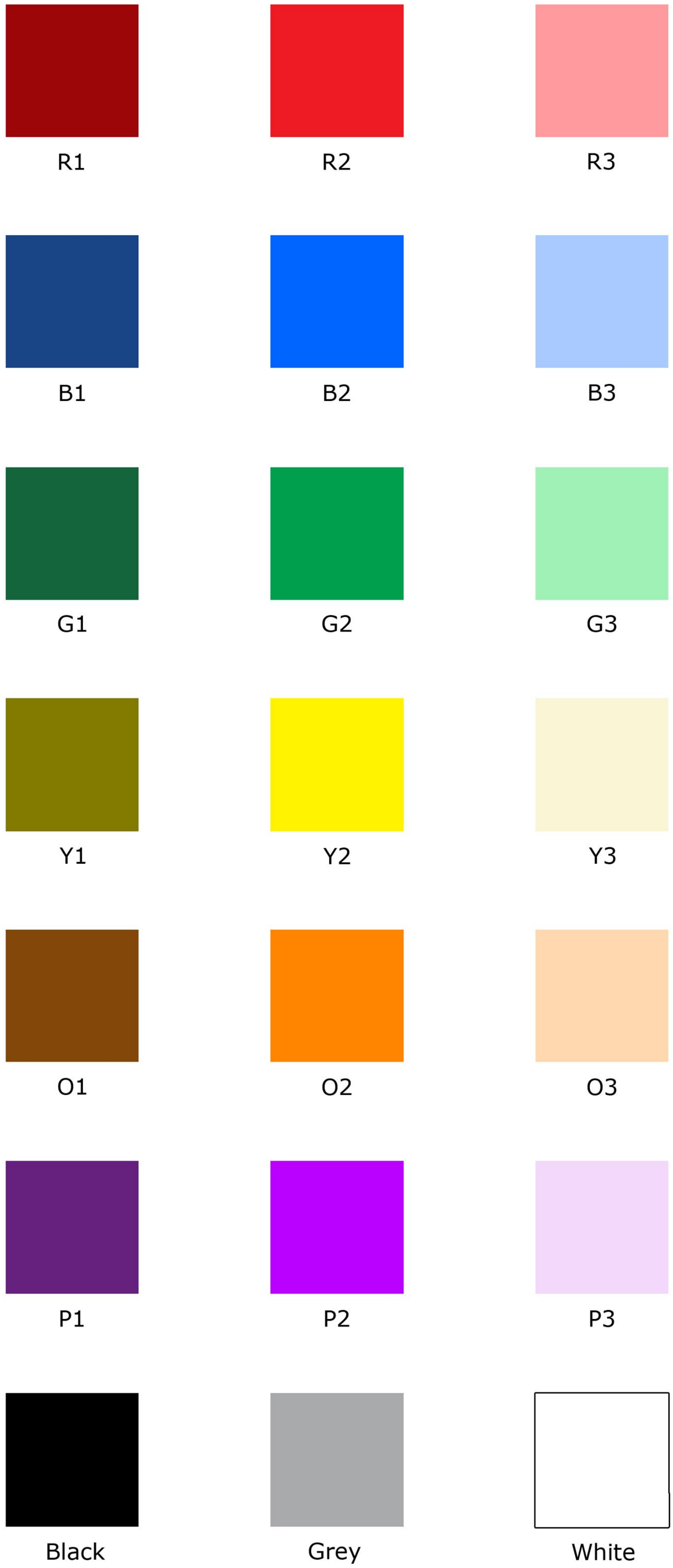
Marianne Patera
m.patera@gsa.ac.uk

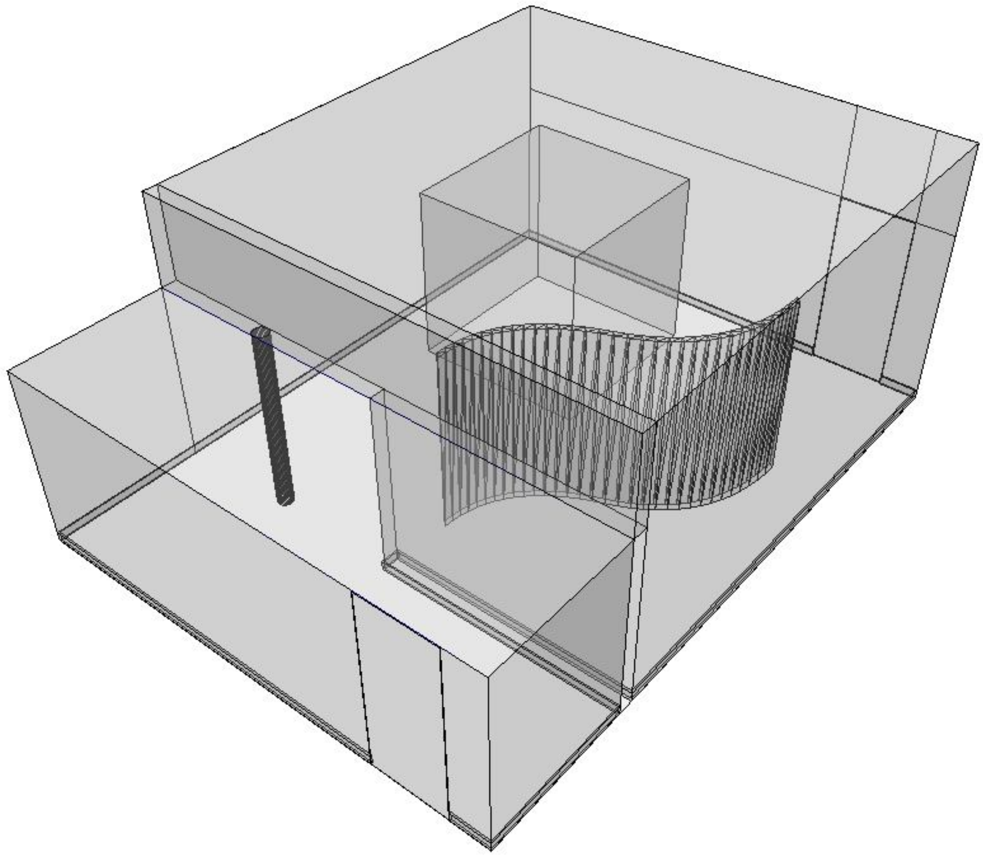
Consent Form

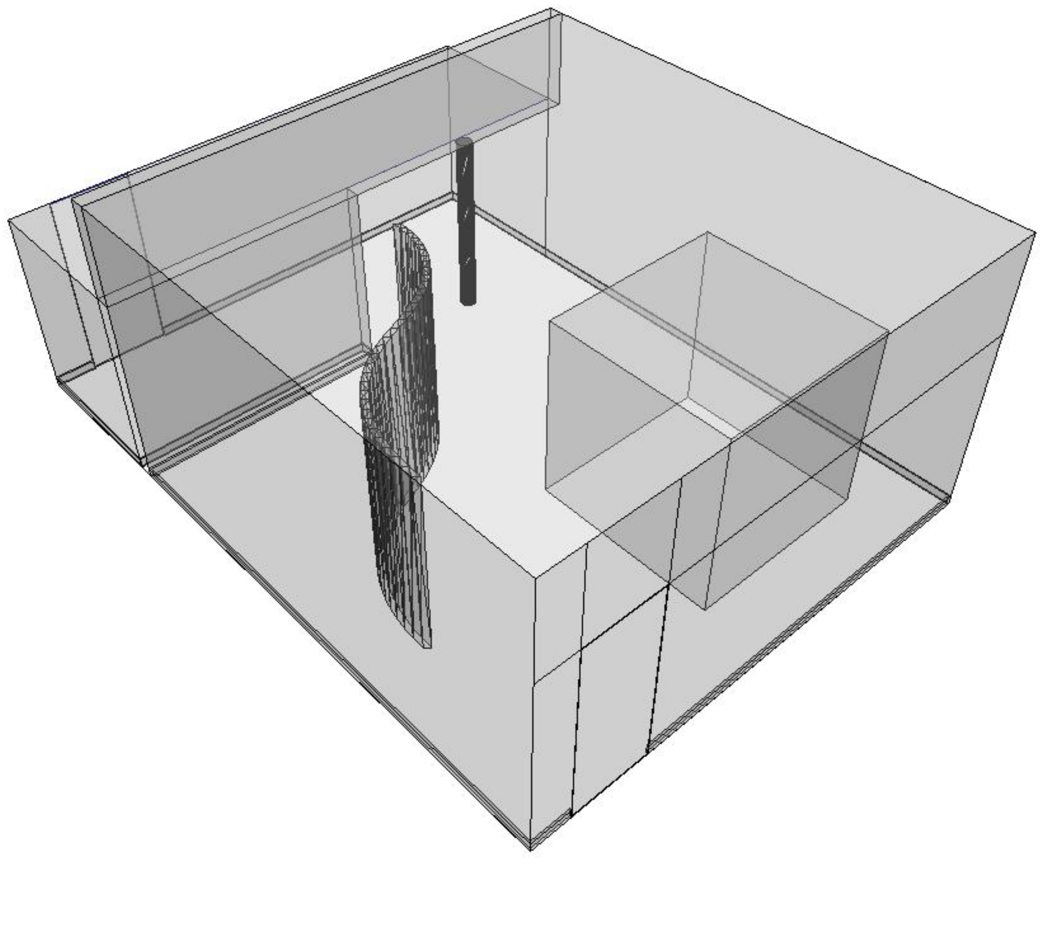
I have read this information sheet and I agree to voluntarily take part in this study:

Name: ______________________________

Signature: ______________________ Date: ______________


R1
R2
R3
B1
B2
B3
G1
G2
G3
Y1
Y2
Y3
O1
O2
O3
P1
P2
P3
Black
Grey
White





Name: ______________________________

Age: ____

Email: ______________________________

Q1: Which colours have you chosen?

1.______ 2.______ 3.______ 4.______ 5.______

Q2: What is the idea behind your design?

Consent form and questionnaire given to the students upon arrival at the DDS (second session, stage 1):

Consent Form

This interview concerns the VR Colour activity in which you participated during the first term. We wish to gather some further information regarding your experience with the VR technology. The interview will be digitally recorded and transcribed (it will be typed up and anonymised). All data collected from you will be treated with full confidentiality as they will be coded in such a way that your identity will not be identifiable as your own.

Participation in the interview is voluntary, and should you wish to withdraw participation at any point you may do so without having to provide a reason. The results of this research may be published but your name will not be associated in any way with the findings.

If you require further information about this study please do not hesitate to contact me.

Thank you for your time.

Marianne Patera

m.patera@gsa.ac.uk

Consent Form

I am aware that my participation in this interview is voluntary. I give my permission for this interview to be audio taped. If, for any reason, at any time, I wish to stop the interview, I may do so without having to give an explanation.

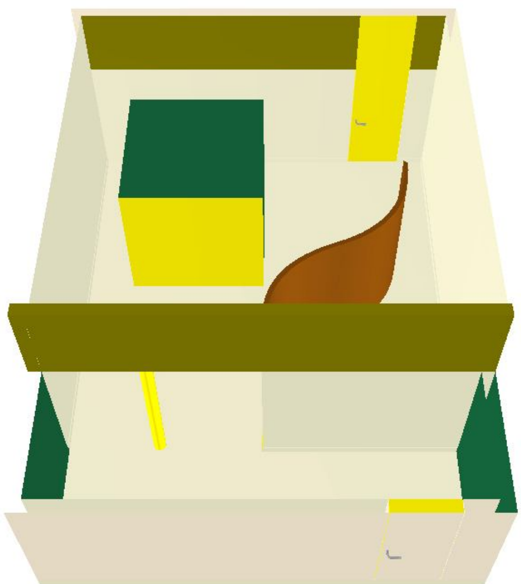
Name: ______________________

Signature: ______________________ Date: ______________________

You have chosen the following colours:

1. Do you believe that certain colours are associated with certain emotions? Can you provide an example?

2. What sort of feeling do you expect your interior will produce?



Questionnaire given to the students at stage 3 prior to the group discussion:

1. How important is colour in your work?

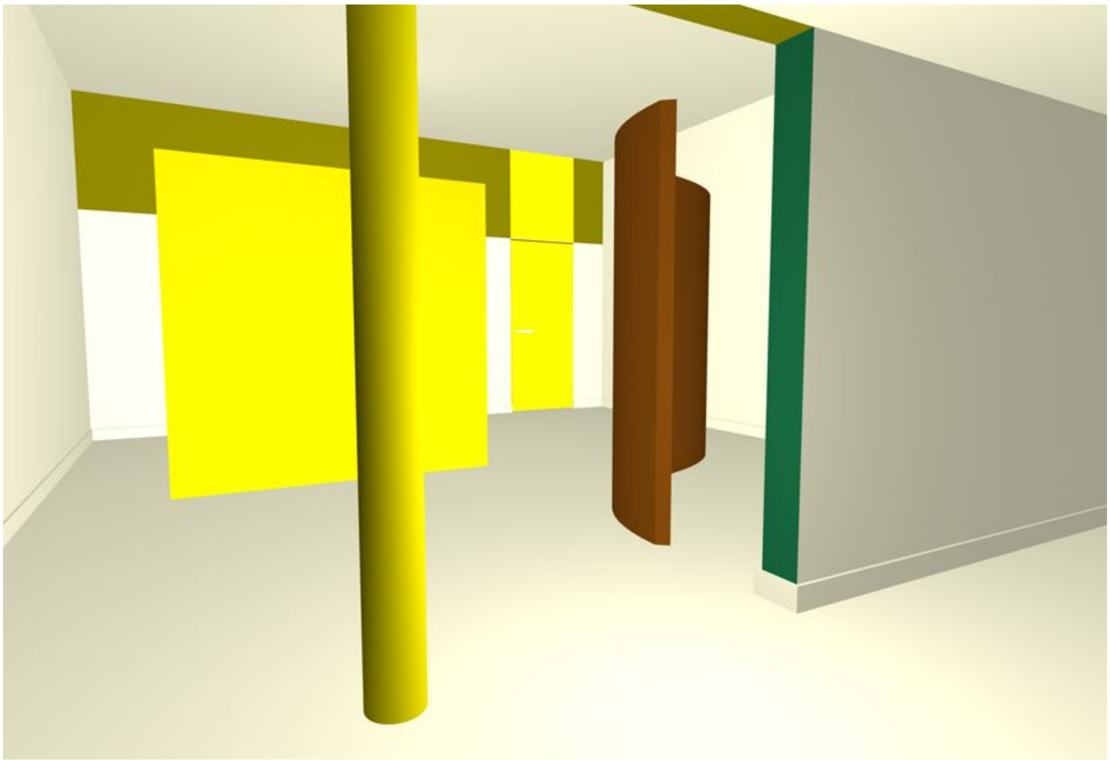
2. Do you normally use colour for aesthetic or practical reasons?

3. When you are choosing a colour scheme for an interior what are your main considerations?

4. Was the visual impact of the chosen colours different when viewed on paper, on the laptop screen and in the Virtual Reality environment?

All coloured 3D rooms

An egocentric view of a 3D room:



Appendix C

Consent form for follow-up Study 3:

Information Sheet

This study is part of a collaborative project between the Interior Design department and the Digital Design Studio of the Glasgow School of Art. The project aims to investigate the use and implementation of virtual environments in interior design education.

The timetable for the study is attached. You will view and explore six different 3D interior models using three displays. You will be asked to answer a brief questionnaire after experiencing each interior and an evaluation form towards the end of the third session before the group discussion.

The sessions will be video and audio recorded for further analysis. All data collected from you will be treated with full confidentiality as they will be coded in such a way that your identity will not be identifiable as your own. The results of this research may be published but your name will not be associated in any way with the findings. Still images from the video recordings may be used in internal reports and external publications.

This study does not form part of any assessment for your course. Participation in the study is voluntary, and should you wish to withdraw participation at any point you may do so without having to provide a reason.

If you require further information about this study please do not hesitate to contact us.

Thank you for your time.

David Nutter
Interior Design
d.nutter@gsa.ac.uk

Mairghread McLundie
Digital Design Studio
m.mclundie@gsa.ac.uk

Consent Form

I have read and understood this information sheet and I agree to voluntarily take part in this study:

Name:

Signature: Date:

Rating scale for the three displays:

Please answer the following questions by circling the appropriate number.

question 1	How well do you think the display conveyed the actual size of the interiors?				
normal	**1**	**2**	**3**	**4**	**5**
wide	**1**	**2**	**3**	**4**	**5**
stereo 3D	**1**	**2**	**3**	**4**	**5**
	very well	well	ok	badly	very badly

Comments ....
(optional)
....

question 2	How comfortable did you feel when viewing the display?				
normal	**1**	**2**	**3**	**4**	**5**
wide	**1**	**2**	**3**	**4**	**5**
stereo 3D	**1**	**2**	**3**	**4**	**5**
	very comfortable	comfortable	ok	uncomfortable	very uncomfortable

Comments ....
(optional)
....

question 3	How would you rate the navigation inside the models with each display?				
normal	**1**	**2**	**3**	**4**	**5**
wide	**1**	**2**	**3**	**4**	**5**
stereo 3D	**1**	**2**	**3**	**4**	**5**
	very easy	easy	ok	difficult	very difficult

Comments ....
(optional)
....

question 4	How immersed did you feel in the interiors?				
normal	**1**	**2**	**3**	**4**	**5**
wide	**1**	**2**	**3**	**4**	**5**
stereo 3D	**1**	**2**	**3**	**4**	**5**
	very immersed	immersed	ok	not very immersed	not at all immersed

Comments ....
(optional) ....

question 5	Which type of display did you prefer?		
	normal	***wide***	***stereo 3D***
Please tell us why			

question 6

Please tell us
a) what, for you, were the main benefits and drawbacks of each type of display?
b) what do you think the significance/impact of these benefits/drawbacks would be, and why?

	Benefits	Drawbacks
normal		
significance/ impact		

	Benefits	Drawbacks
wide		
significance/ impact		

	Benefits	Drawbacks
stereo 3D		
significance/ impact		

Appendix D

Analysis of questionnaires for follow-up Study 3

The students were asked to rate each display configuration (Normal, Wide, Stereo) on four characteristics:

Q.1 How well do you think the display conveyed the actual size of the interiors?
Q.2 How comfortable did you feel when viewing the display?
Q.3 How would you rate the navigation inside the models with each display?
Q.4 How immersed did you feel in the interiors?

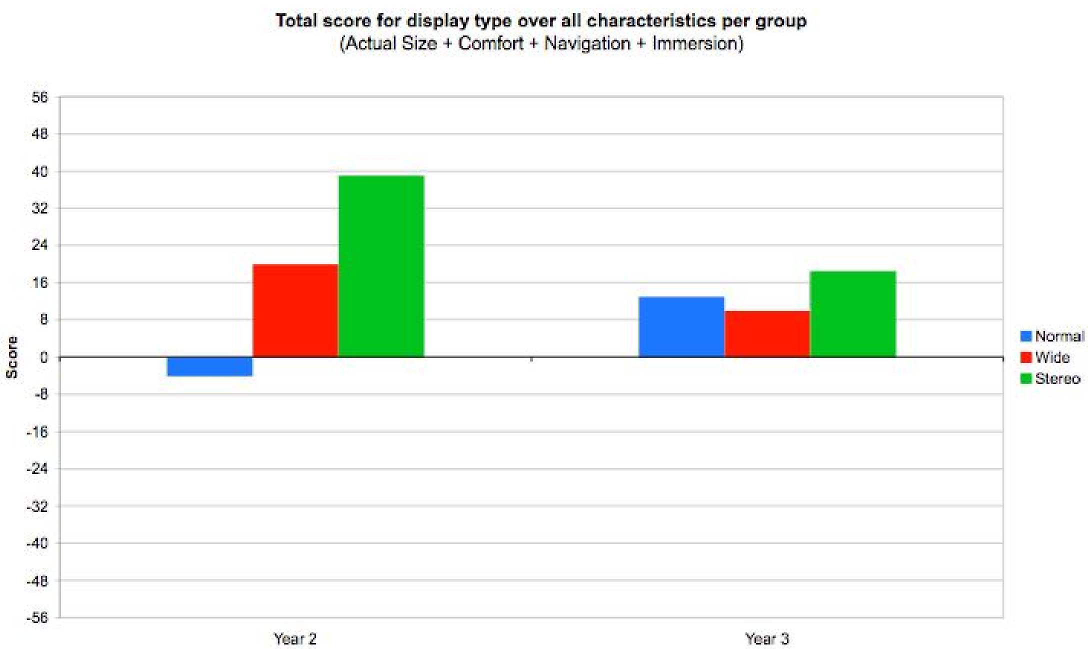
For each of these characteristics (termed Actual Size, Comfort, Navigation & Immersion), students were asked to rate the displays on a five point scale. For the purposes of further analysis, all the students' ranked responses were scored from 2 (best score) to -2 (worst score).

The graphs in this report follow the following conventions:

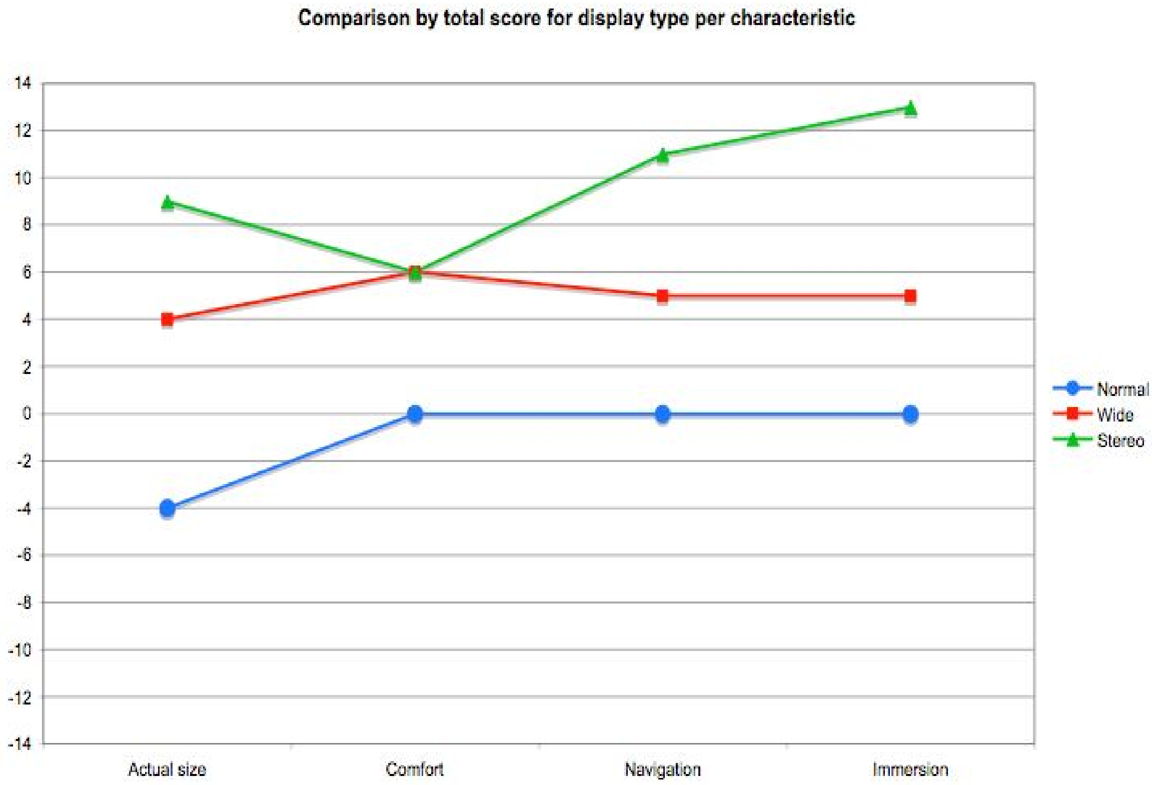
Normal configuration Wide configuration Stereo 3D configuration

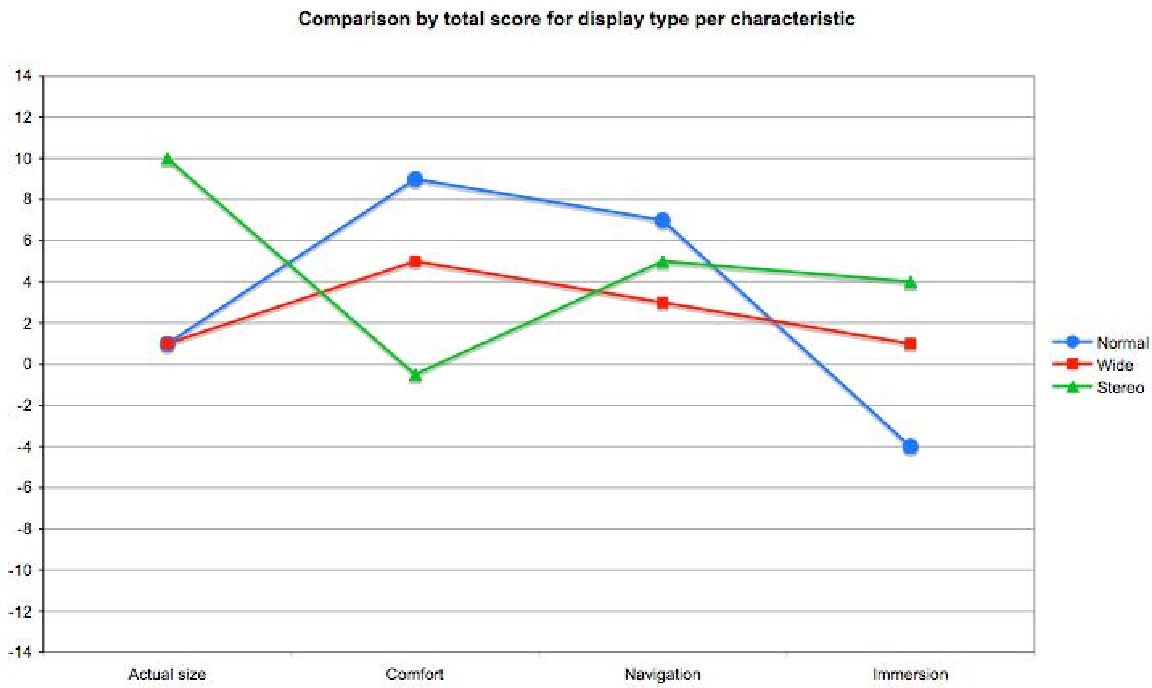
Actual Size Comfort Navigation Immersion

Ratings of displays

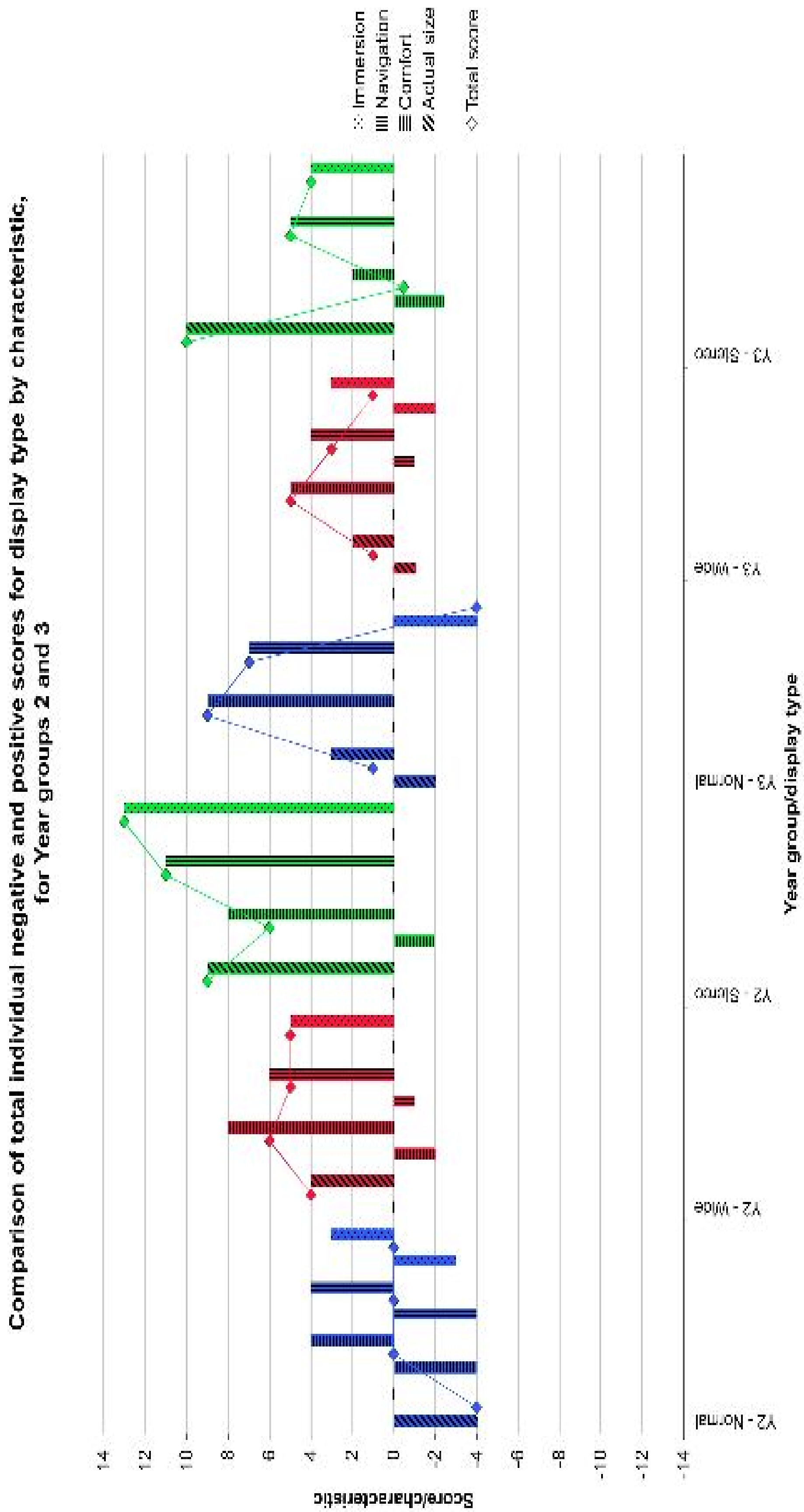


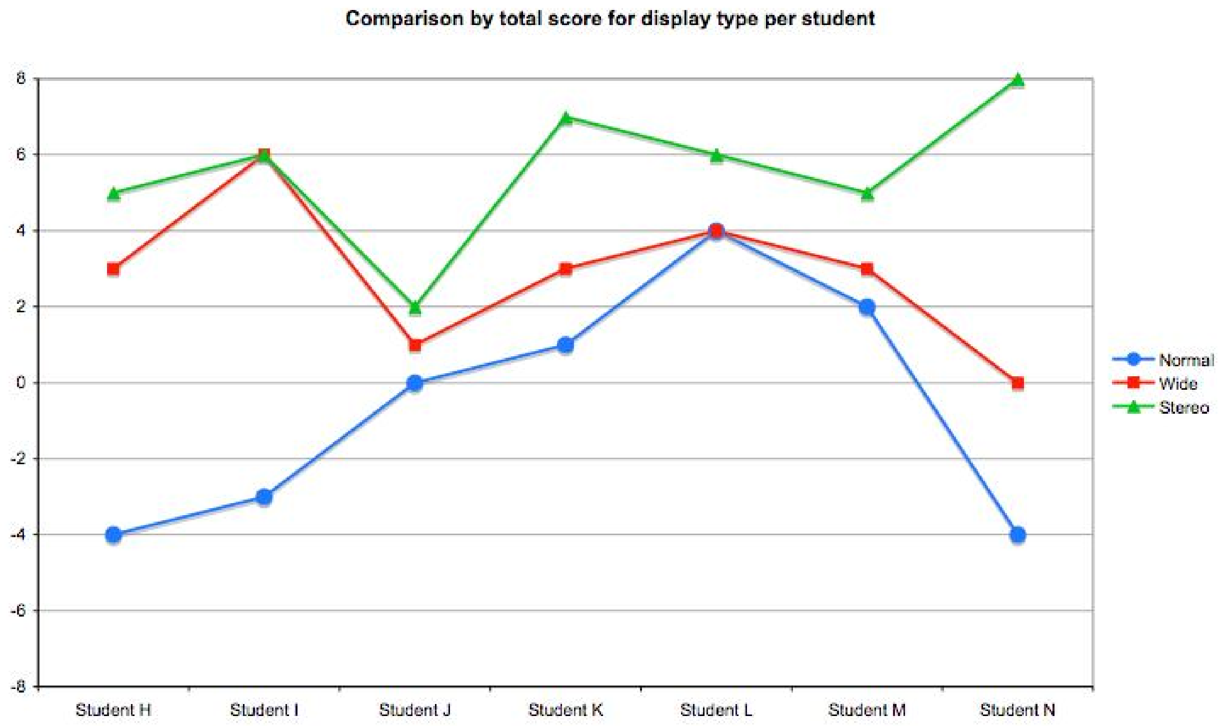
Total score for each display type for Years 2 & 3

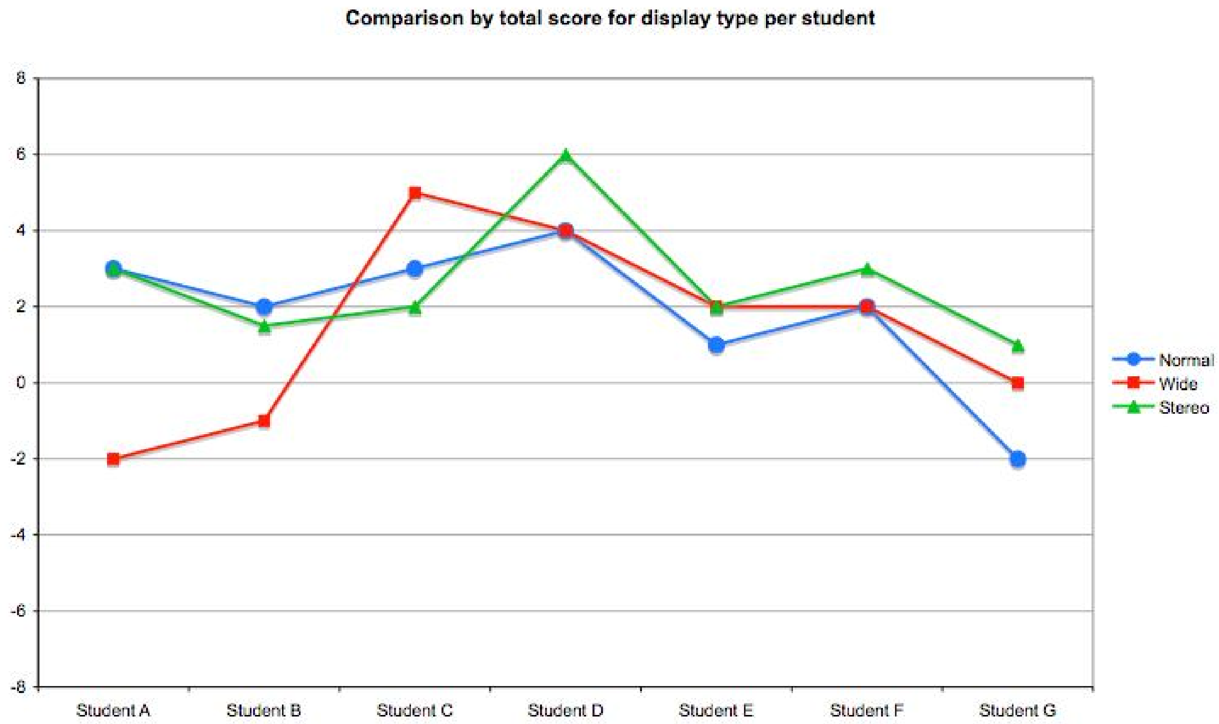




Comparison of total score for characteristic per display type
for Year 2 (above) and Year 3 (below)


Comparison of total individual negative and positive scores for display type by characteristic, for Year groups 2 and 3
Immersion
Navigation
Comfort
Actual size
Total score
Score/characteristic
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Y2 - Normal
Y2 - Wide
Y2 - Stereo
Y3 - Normal
Y3 - Wide
Y3 - Stereo
Year group/display type





Total score for display configuration per student for Year 2 (above) and year 3 (below)

There were differences of opinion within and between groups, but the themes identified below are those on which there was a degree of consensus.

Points to note from reading the graphs:

- the Stereo 3D configuration was rated most highly overall by both groups
- Year 3 scored the three display configurations much more closely than Year 2
- Year 2 rated the Normal configuration negatively overall; as mentioned above, during the start of the first review session (Normal configuration) with this year group
- both groups ranked Stereo best for Actual Size and Immersion
- both groups ranked Normal lowest for Immersion
- in both year groups, the only characteristic that students scored at all negatively in the Stereo configuration was Comfort

Normal display

Benefits

- easy to use and to navigate within the space
- users can sit anywhere and view the display comfortably
- can be used comfortably for long periods of time without causing eye strain
- shows basic form well; can easily check how the design works; still get a good idea of the volumes in space and textures
- quickest way to see spatial volumes and their arrangements in space
- is nearer to the design on CAD; good to see the work at larger scale

Drawbacks

- image quality is not as good - doesn't give an extremely crisp, rendered visual
- poorer representation of colour, textures and materials
- didn't convey the same depth as the other displays
- view too narrow; bad perspective of space - confusing and dishonest; hard to situate yourself within the interior; is confusing, disorientating, confuse floors, walls and ceilings; difficult to get a good impression of the space and hard to read the building (at the start of the Year 2 review session using the Normal configuration, it became clear that the angle of view was too narrow. Although this was resolved for subsequent designs, it may have heavily influenced the following remarks which were made by this group.)

Remarks

- good for group work - everyone can see well and the display can be used comfortably by most people for longer periods of time
- is a good next stage after the CAD design, to see the work at larger scale and to quickly check spatial volumes and their arrangements in space
- less good for experiencing the space and interior
- a system which is easy to use and useful for checking basic form and to get a good appreciation of the volumes in space

Wide display

Benefits

- gives a good impression of the overall space and how the elements within it relate to one another
- the wider field of view - peripheral vision - gives a more realistic point of view; larger scope and view of interior space; it allows you to see what's beside you, and makes you more aware of your surroundings, as you have a good sense of what's there
- comfortable to view the whole space; some students found it easier to navigate and move around in the space
- when you stand closer to the display, you do feel immersed
- gives a good experience of the space
- fewer problems with eye strain

Drawbacks

- misrepresentation of the dimensions of the space (it stretches the space, makes it look bigger and more spacious than it actually is); spatial distances are complicated to judge, as the display gives a totally different impression of how the interior works in 'real life; quite hard to determine correct size and dimensions of each room space
- distortions of image, particularly at the edges, and especially if you're not sitting or standing in the ideal viewpoint or 'sweet' spot; this seemed to be more or less of a problem depending on the individual
- you have to sit or stand in the right place to get the proper viewpoint, otherwise it can be uncomfortable, cause eye strain, or distort the image further
- a slight strobing *[at the join of the two screens]* when you move your head or blink detracts from the immersion and leads to a headache
- although you have the benefits of peripheral vision, every element in the space is in focus, unlike in real sight; this creates a distraction on the wider angles

Remarks

- good for getting a good overall understanding of the space and how individual elements within it relate to one another
- does not provide an accurate representation of the space in terms of dimensions
- good for individual work, less useful for group work

Stereo 3D display

Benefits

- most accurate representation of colours, materials and textures
- most accurate representation of space, including size, depth, volume and structure; better grasp of how much space you had to move around in
- high quality image - crisp, clear, sharp, detailed; image more concise and engrossing
- good experience of the space; perception of interior far better
- most convincing; closest simulation to reality; realistic, feeling of being inside the space, wanting to reach out and touch objects

Drawbacks

- uncomfortable to use for long periods of time
- sometimes hard for eyes to adjust; eye strain after looking at the display for a long time
- feelings of nausea and dizziness (standing further back helped some students); 3D effect can be disorientating; moving too quickly can make viewers feel faint or nauseous
- you only get a really good view when sitting or standing directly in front of the screen - elsewhere you can't see as well and it can feel uncomfortable; you can 'lose' the image, or lose the quality of the image, from time to time
- wearing glasses ("sunglasses") affects communication within the group

Remarks

- good for individual use, not good for groups
- good for final presentations of design
- good for representations to clients, or for the designer, when you want accurately to convey the space, and the experience of being in the space

Appendix E

This is a proposed specification for setting up an immersive 3D virtual studio.
The following setup provides a flexible two-projector configuration for normal, widescreen and passive 3D stereo displays.

Software: a 3D modelling software package (In this research VectorWorks was used because the interior department was already using that software)

OpenSceneGraph (open source software)

DesignViewer software (presented in Appendix F) or another software that facilitates the process of importing the 3D models from the 3d modelling software package to OpenSceneGraph (e.g. EON Reality's Deep Exploration)

Equipment: A high specification computer

Two ceiling-projectors.

Polarising filters to place in front of the projectors

Joystick or other navigation control device

Polarised 3D glasses

Other: Special silver paint for the wall surface

Blinds or curtains to block sunlight

Appendix F

DesignViewer – Software Documentation Version 1.0 – Nov. 2008

Introduction
This document describes the DesignViewer software tool developed by Martin Naef at the DDS. DesignViewer is a software environment to visualise and explore 3D models using a range of display devices. The tool has been designed for maximum ease of use and is optimised to display models generated using Vectorworks.

Software Architecture and Components
DesignViewer has been developed with Visual C++ using OpenSceneGraph as the rendering engine and TinyXML to parse configuration files. There are no other external dependencies. DesignViewer currently relies on Windows for the joystick interface; there are no other platform-dependencies.
Although the software has been built for a specific application, some effort was put into making the system configurable and therefore suitable to a range of applications and display systems.

Application
DesignViewer.exe is the main application. It is a console application that takes a range of parameters, namely the 3D scene file to display and optional links to configuration files.

Configuration Files
All configuration data is stored in basic (human readable) XML files. Although all configuration items could be stored in a single file, they are kept separate to avoid too large a collection of files when changing display or device configurations.
Configuration is split into Device (display type and size, joystick), Render (shadow and light), and Scene (file loading options).

Scene Files
The scene or model files contain the actual 3D model to be displayed. They can be in any file format understood by OpenSceneGraph, although the workflow has been optimised for the 3DS format as exported from Vectorworks, with other file types likely to result in artefacts depending on the scene configuration options.

Usage
The application is started from the console prompt with the following parameters:
```
DesignViewer [--DeviceConfig file.xml] [--RenderConfig file.xml] [--SceneConfig file.xml] 3dfile.3ds
```
The --DeviceXXXX settings are optional and override the default configuration files. Several 3d files can be specified to assemble a scene from various components. A range of options as described in the OpenSceneGraph documentation are available as well, although sensible defaults have been selected in the application.
In the minimal case, only the 3d scene file is specified, the configuration options are read from the current directory.

Configuration Files

Device Configuration
The device configuration file includes the settings for the display and joystick hardware. By default, the file DeviceDefault.xml is loaded from the current directory.

`<DeviceConfig>` Section
This the main group in the XML file and brackets all the other options listed below.

`<Display>` Section
This section includes the physical configuration of the screen and rendering mode.

`<ScreenWidth> <ScreenHeight> <ScreenDistance> Options`

Defines the width, height and distance of the projection screen in m. ScreenDistance can be optimised to change the field of view.

<Stereo> Option
This defines the stereoscopic rendering mode. Valid options are no (standard mono visual), active (field-sequential active stereo) and passive (for use with passive stereo glasses).

<Monitor> Option
This option defines where to render the view. Valid options are window (a standard window is used for rendering), 0 (full screen on the primary display), 1 (full screen on the secondary display), and dual (spans both primary and secondary display for wide screen or passive stereo).

<Joystick> Section
This section includes the configuration for the joystick and navigation.

<Name> Option
This is used to select the attached joystick. The first device that includes the string from the name option is selected. An empty string means the first device is selected.

<NavigationMode> Option
This selects the navigation mode. Default is Simple, which moves the user when button 1 is pressed, and rotates otherwise. Extended uses a direction or POV switch to rotate, and the main joystick to move.

Device Configuration-Sample

```
<?xml version="1.0" encoding="utf-8"?>
<!-- The default configuration file for the devices - this is loaded unless
another one is specified-->
<DeviceConfig>

        <Display>
                <ScreenWidth>3.2</ScreenWidth>
                <ScreenHeight>1.8</ScreenHeight>
                <ScreenDistance>1.25</ScreenDistance>

                <!-- Stereo options: no | active | passive -->
                <Stereo>no</Stereo>

                <!-- Monitor options: window | 0 | 1 | dual (0/1/dual are all
        full screen options) -->
                <Monitor>window</Monitor>

        </Display>

        <!-- Configuration for the joystick -->
        <Joystick>
                <!-- Defines the name (part of) that is used to find the
        joystick -->
                <Name>Attack</Name>
                <!-- defines the navigation mode: Simple or Extended (needs a
        direction switch) -->
                <NavigationMode>Simple</NavigationMode>
        </Joystick>
</DeviceConfig>
```

Render Configuration

The render configuration file sets up basic lighting and shading parameters. By default, the file RenderDefault.xml is loaded from the current directory.

<RenderConfig> Section
This the main group in the XML file and brackets all the other options listed below.

<Shadow> Section
The shadow section defines the options for shadow rendering.

<Type> Option
Defines the shadow type: none (no shadows are rendered), hard (basic shadows) and soft (soft shadows). Soft shadows currently suffer from implementation bugs in the OpenSceneGraph version used and are not recommended.

<AmbientWeight> <DiffuseWeight> Options
These options define the strength of the shadows and can be used to tweak the look.

<MapResolution> Option
Defines the resolution of the shadow map. The value must be a power of two. Higher values lead to finer shadows but may exceed available memory. Typical values are 1024, 2048 or 4096.

<Light> Section
The light sections define light sources. Theoretically, several lights can be defined, although the current OpenSceneGraph implementation seems to ignore any but the last light.

<Position> Section
<x> <y> <z> set the position or the direction of the light. If <w> is set to 0, xyz defines the direction vector. A <w> of 1 means that xyz is the position of a point light source.

<Ambient> <Diffuse> <Specular> Options
These options set the power of the light source for ambient light, diffuse and specular. Values must be between 0 and 1. They can be used to tweak the overall scene brightness and the strength of shading.

Render Configuration – Sample

```
<?xml version="1.0" encoding="utf-8"?>

<RenderConfig>
	<!-- configuration for the shadow system -->
	<Shadow>
		<!-- shadow types: none, hard, soft -->
		<Type>none</Type>
		<!-- shadow configuration - ignored if type is none -->
		<AmbientWeight>.4</AmbientWeight>
		<DiffuseWeight>.8</DiffuseWeight>
		<MapResolution>4096</MapResolution>
	</Shadow>
	<!-- define a light source -->
	<Light>
		<!-- Position of the light - a W value of 0 means a directional
	light, xyz then becomes the direction vector -->
		<Position>
			<x>.5</x>
			<y>.25</y>
			<z>.8</z>
			<w>0.0</w>
		</Position>
		<!-- Intensities for ambient, diffuse and specular component -->
		<Ambient>0.25</Ambient>
		<Diffuse>.8</Diffuse>
		<Specular>0.25</Specular>
	</Light>

</RenderConfig>
```

Scene Configuration

The scene configuration defines a range of loader options and the environment in which the model is rendered. By default, the file SceneDefault.xml is loaded from the current directory.

<SceneConfig> Section

This the main group in the XML file and brackets all the other options listed below.

<Scale> Option

Defines the overall rescale-factor of the scene. 3DS files are exported in mm from Vectorworks and need to be rescaled to m (factor: 0.001). Scaling will go wrong if the model is exported with translation groups – in this case, a factor of 1 must be used to disable rescaling.

<Cull> Option

Enables or disables (on / off) backface culling. Disabling culling introduces a performance penalty and may result in z-fighting artefacts. However, in many cases it fixes issues with flipped normals resulting in holes.

<ResetNormals> Option

on forces a recalculation of the normals of all surfaces. Normal recalculation is only implemented for triangle type geometry, which seems to be fine for 3DS models. Normal recalculation does not produce smooth surfaces but seems to look a lot better on all models tested, as the default 3DS import generates weird looking normals for architectural models.

<FlatShading> Option

on forces flat shading on all surfaces. FlatShading can reduce artefacts from import for those models where ResetNormals doesn't work.

<TwoSided> Option

on forces two-sided light calculation and reduces problems caused by flipped surface normals. This has proven to be a problem-solver for most models.

<ResetAmbient> Option

on forces the ambient colour value of all material to be the same as diffuse. This is generally recommended unless ambient colour has been specifically optimised for a scene.

<Sky> Option

This option enables to specify and load a 3D file used as scene background. Typically, this would be a large sphere with a sky texture. It can be in any 3D file format recognised by OpenSceneGraph. Leave empty to disable.

<Ground> Option

This option specified an image file used as texture for the ground plane. Leave empty to disable.

<Base> Option

This option defines the scale for the simple base geometry to be placed below the model. 1 uses the bounding box as the size. 0 disables the base plane.

<Ceiling> Option

This option defines the scale for a simple "roof" geometry to be placed on top of the 3D model. 1 uses the bounding box as the size, 0 disables it completely. This geometry does not cast shadows.

<DefaultPosition> Section

<x> <y> <z> <h> define the initial position and heading where navigation starts. This option ensures a sensible starting place for the navigation.

Scene Configuration – Sample

```
<?xml version="1.0" encoding="utf-8"?>

<!-- The default configuration file for the scene - this is loaded unless
another one is specified-->
<SceneConfig>

	<!-- Overall model scale (1 for modified models, 0.001 for 3DS
(exported in mm) -->
	<Scale>0.001</Scale>

	<!-- enable / disable backface culling for this particular model
(on/off) -->
	<!-- Disabling culling can solve issues with flipped normals, but may
cause other issues (z-fighting) -->
	<Cull>on</Cull>
	<!-- Reset the normals for the model (flat shaded) (on / off) -->
	<ResetNormals>on</ResetNormals>
	<!-- Force flat shading) (on / off) -->
	<FlatShading>on</FlatShading>
	<!-- Enable / disable two-sided lighting (on/off) -->
	<TwoSided>on</TwoSided>
	<!-- Reset the ambient color values to be the same as diffuse -->
	<ResetAmbient>on</ResetAmbient>

	<!-- Define the model to be loaded as sky (scene file) - leave empty to
disable -->
	<Sky>Model/sky/SkyDome.ive</Sky>
	<!-- define the texture used for the ground-leave empty to disable -->
	<Ground>Model/sky/grass20.jpg</Ground>

	<!-- base and ceiling geometry - defined as size factor relative to
bounding box, leave empty or 0 to disable -->
	<Base>2</Base>
	<Ceiling>1.1</Ceiling>

	<!-- the default viewer position where the visualisation starts -->
	<DefaultPosition>
		<x>1</x>
		<y>0</y>
		<z>1.5</z>
		<h>45</h>
	</DefaultPosition>

</SceneConfig>
```

Appendix G

List of software packages used in this research:

Autodesk Maya:

3D modelling software

http://www.autodesk.co.uk/adsk/servlet/index?siteID=452932&id=11646831

VectorWorks:

3D modelling software

http://www.vectorworks.uk.com/vw/index.jsp

VEGA:

Real-time 3D application development

http://www.vis-sim.org/products/runtime/vega_prime/index.shtml

EON Studio:

2D & 3D authoring software

http://www.eonreality.com/products_studio.html

Right Hemisphere's Deep Exploration, Standard Edition:

2D & 3D authoring software

http://www.righthemisphere.com/products/dexp/de_std.html

OpenSceneGraph:

Open source high performance 3D graphics toolkit,

http://www.openscenegraph.org/projects/osg

Appendix H

Publications during the course of this research:

Patera, M., McLundie M., Naef M. & Nutter, D. (2009). Experiencing Space: an Immersive VR Environment for Interior Design Students. [To be presented] at *CAL 09 Conference, Learning in Digital Worlds*, 23-25 March, Brighton, UK.

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Charissis, V., Naef, M., Papanastasiou, S. & M. Patera (2007). *Designing a Direct Manipulation HUD Interface for In-Vehicle Infotainment, Book title: Human-Computer Interaction.* Interaction Platforms and Techniques, Lecture Notes in Computer Science, Volume 4551/2007, Springer Berlin/Heidelberg, pp. 551-559

Charissis, V., Nomicos, S. & Patera, M. (2007). *Prototype System for Virtual Reality Simulation and Training: Initial Implementation for Large Printing Units*. 3rd International Conference on Typography and Visual Communication, ICTVC 07, From Verbal to Graphic, 20-23 June, Thessaloniki, Greece.

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Charissis,V., Papanastasiou, S. & Patera, M. (2007). *Human Machine Interface for Prototype Head Up Display: Comparative study between 2D and VR Simulation Results*. In proceedings of Transport Science and Technology Congress, TRANSTEC '07, Prague, Czech Republic.

Patera, M. & Draper, S.W. (2007). *Immersive 3D visualisation and teaching colour use to interior designers.* CAL 07, Development, Disruption & Debate. 26-28 March, Trinity College, Dublin, Ireland.

Patera, M., Naef, M. & Draper, S.W. (2006). *The Magic Cottage: A Virtual Reality Environment for Stimulating Children's Imaginative Writing.* In proceedings of the 4th International Narrative and Interactive Learning Environments Conference, NILE 06, 8-11 August, Edinburgh, UK, pp. 67-75

Patera, M., Draper, S.W. & McWhirr, M. (2005). *A Novel Approach to Colour Education and Comparative Testing of Physical and Digital Versions.* In proceedings of Designs on e-learning, 1st International Conference on Teaching and Learning with Technology in Art Design and Communication, 14-16 September, London, UK.

Patera, M., Draper, S.W. & McWhirr, M. (2005). *Using educational theory and advanced technology in colour education*. In proceedings of the 10th Congress of the International Colour Association, AIC 05, 8-13 May, Granada, Spain, pp. 77-80

Glossary

Avatar: (1) a virtual object used to represent a participant or physical object in a virtual world; the representation may take any form. (2) the object embodied by a participant. (Sherman & Craig, 2003, p. 13)

CAVE: (Cave Automatic Virtual Environment) is a virtual reality environment consisting of a cube -shaped room in which the walls are rear-projection screens. The CAVE is contained within a larger room that must be absolutely dark when the CAVE is in use. 3D visuals within the cave appear to float in mid-air. The viewer, who wears special glasses synchronized with the projectors, can walk around the virtual environment to study it from all angles. A research team at the University of Illinois at Chicago developed the first CAVE and demonstrated it at the 1992 SIGGRAPH conference (Cruz-Neira et al. 1993).

Colourimetry: is the science of measuring colours.

Constructivism: is an educational theory that is founded on three broad principles based on the theories of Dewey, Piaget and Vygotsky. The first principle is that each person constructs their own understanding of the world and builds his/her own personal representation of knowledge. The second principle is that learning occurs during active exploration of the knowledge domain (this is attributed to Piaget). The third principle, normally attributed to Vygotsky (1978), is that learning occurs within a social context, and that interaction between learners is an essential part of the learning process. (Dalgarno, 2001, p. 184)

Gamut: in colour reproduction, including computer graphics and photography, the gamut, or colour gamut is a certain *complete subset* of colours. The most common usage refers to the subset of colours which can be accurately represented in a given circumstance, such as within a given colour space or by a certain output device. (http://en.wikipedia.org/wiki/Gamut)

Hue: is the quality we identify by a colour name, such as 'red' or 'purple'. It corresponds to the distinctive wavelength of a colour. (Zelanski & Fisher, 1999, p. 18)

Immersion: is the sensation of being in an environment; can be a purely mental state or can be accomplished through physical means; physical immersion is a defining characteristic of VR. (Sherman & Craig, 2003, p. 9)

Learning event: this term describes a learning and teaching activity. The educational technology in this study was designed and employed to assist both learners and tutors; this has been described as a 'learning event-centred approach'.

Presence: short for sense of presence; similar to being mentally immersed (see Immersion above).

Radiosity: A method for rendering a view of a three-dimensional scene that provides realistic lighting effects, such as inter-object reflections and colour bleeding. Radiosity methods are computationally intense, due to the use of linear systems of equations and the spatial complexity of large scenes. (http://dictionary.die.net/radiosity)

Saturation: the degree to which colours are greyed by being mixed with their complementaries. It is also known as 'Intensity'. In their purest, most brilliant state, colours are at maximum saturation; as they become more and more neutral, they are said to be lower in saturation. (Zelanski & Fisher, 1999, p. 18)

Spatially immersive display: the term is defined in this thesis as a display which covers all or a big percentage of a user's field of view. The normal horizontal field of view for a human is approximately 200 degrees. The display's field of view is a measure of the angular width of a user's vision that is covered by the display. The display can be either viewed with stereo or passive glasses or with no glasses.

Stereopsis or Stereoscopic Image Depth Cue: The term derives from the parallax between the different images received by the retina in each eye (binocular disparity). The stereoscopic image depth cue depends on parallax, which is the apparent displacement of objects viewed from different locations (Sherman & Craig, 2003, p. 119). In essence, stereopsis is the ability to interpret two separate images as the same image, with depth information.

Value: is the degree of lightness and darkness in a colour, and in pigment mixtures it can be adjusted by the addition of black or white. It is also known as 'brightness' when light mixtures are being discussed. (Zelanski & Fisher, 1999, p. 19)

Virtual Environment or Virtual World: the term virtual environment is often used as a synonym of both virtual reality and virtual world. Virtual environment is ambiguous in that it can be defined as a virtual world or as a world presented in a particular virtual reality hardware configuration (Sherman & Craig, 2003, p. 16). In this thesis a virtual environment has been defined as a computer-generated, graphically rich 3D world inside which the user can explore and perform actions (e.g. interact with the virtual objects) using any type of hardware configuration.

Virtual Reality: a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (the virtual world). (Sherman & Craig, 2003, p. 13)

List of Abbreviations

3D: Three-dimensional

CAD: Computer Aided Design

CAVE: Cave Animated Virtual Environment

DDS: Digital Design Studio

GSA: Glasgow School of Art

HMD: Head-Mounted Display

HSV: Hue, Saturation and Value

IDS: Interior Design Student

IDT: Interior Design Tutor

LBE: Learning by Exploration

SQ: Socratic Questioning

VE: Virtual Environment

VLE: Virtual Learning Environment

VR: Virtual Reality

VRML: Virtual Reality Modelling Language

WP: Wall Projection

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