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Improving student radiographers' anatomical knowledge using immersive visualization technology

Background and rationale

The success of many clinical tasks from simple physical examinations, through treatment set-ups to radiological interpretation is very dependent upon radiographers' ability to appreciate the spatial relationships between anatomical structures. Developing a detailed understanding of anatomy is therefore essential to radiography students. The importance of developing such knowledge is implicit in the CoR's Curriculum Framework document (2003), its current revision – 'The Learning and Development Framework for Clinical Imaging and Oncology' and also the CoR's Education Strategy document (2005) which highlights the primary role that radiographers play in the acquisition, manipulation and analysis of anatomical data (using ionising and non ionising radiation). Ensuring that students have the requisite knowledge to do this is imperative.

However, the building of a 3D mental map (a vital construct in understanding fully the structure of body parts) presents a significant challenge to both learners and educators. Traditionally, the use of cadavers has traditionally been held as the gold standard (Johnson 2002) but these are used less frequently now and anatomy is increasingly taught as a 'multimedia' experience. Plastic anatomical models are widely used to enhance students understanding of anatomy but these have some limitations, such as the need to spend time cross-referencing small printed labels with an accompanying list of structures.

A number of studies have reported the development and evaluation of virtual reality environments (VRE's) for learning gross and spatial anatomy. Shim et al. (2003) found that students who had learnt about the structure and function of the eye using interactive 3D representations on desktop PCs demonstrated significantly better assessment scores compared to those who had used just 2D multimedia. This was attributed to active participation and immersion in the learning activities inherent in the VRE. Conversely, however, Linton, Schoenfeld-Tacher and Whalen (2005) did not see any significant improvement in student achievement following engagement in a desktop VR application designed to enhance veterinary students' understanding of the canine head.

Hariri et al. (2004) compared a 3D surgical simulator with standard textbook images for learning shoulder joint anatomy but found no significant difference in attainment scores. However, they failed to fully exploit the potential of a 3D VRE for facilitating *spatial* anatomical knowledge and did not assess this outcome. In any case their finding may actually reflect that the VR application was designed for skills acquisition rather than learning about anatomy.

Garg et al. (1999) and (2001) examined more explicitly the use of a VRE for developing spatial anatomical knowledge. Both works focused on using desktop VR for learning relational anatomy of the carpal bones. The earlier study found that multiple views did not result in an increased spatial awareness of the region when compared to standardised key views and suggested that students were able to develop adequate 3D mental maps from exploration of limited 2D views available in textbooks. However, their computer model allowed for limited student interaction and it is uncertain as to whether their finding could be generalised to other anatomical structures. Interestingly, the study was repeated following a modification of the VR model and produced conflicting results – students randomised to the multiple view model achieved significantly better post test scores. The authors attributed this to the change from a self-rotating object to one that could be manipulated by the user and appears to support the importance of interaction and learner control in VRE's.

The studies commented on above in relation to VR applications are slightly atypical of much of the VR literature which focuses on the applications of the technology rather than educational effectiveness. However, there are gaps within the evidence and some limitations in research design that justify further research. Namely:

1. there is limited evidence of a focus on enhancing *spatial* anatomical knowledge;
2. there is some contention as to whether VREs *can* actually enhance spatial cognition of anatomy;
3. there have been no comparisons of VREs with equivalent physical models in relation to assessing improvement in spatial anatomical knowledge;
4. all previous relevant studies have focussed on employing desktop VR rather than immersive VR, and;
5. some research designs lack rigour mainly through very small sample sizes.

Therefore it is proposed that this research study will develop a virtual, interactive model of a complex 3D anatomical structure (the brain) using an immersive visualisation environment and evaluate its educational potential.

Aims and research questions

Aims

A1 Investigate the potential of an immersive visualisation environment (IVE) for enhancing pre-registration radiography students' understanding of brain anatomy

A2 Design effective learning environments employing immersive visualisation technology

A2 Create a new model for LTA strategies in relation to developing spatial cognition of anatomy for radiography programmes.

Research questions

RQ1 Can IVE's improve spatial cognition of brain anatomy?

RQ2 How does student performance/achievement via the integrated use of an IVE compare to traditional approaches?

RQ3 What characteristics of IVE's help/hinder learning?

RQ4 What differences are there in *how* students learn when using IVE's compared to a traditional approach?

RQ5 What influence do certain characteristics (gender, age, handedness, spatial ability, preferred learning style, baseline knowledge and confidence in computer technology) have on student learning using an IVE?

RQ6 What relationships exist between personal characteristics and students' experiences?

Study design and methodology

A pragmatic randomised controlled trial – pre and post test design – will assess the effectiveness of an interactive IVE model of the brain for enhancing spatial cognition of brain anatomy. Students will undertake a simple self-directed anatomy tutorial using either a plastic anatomical model (control group) or the equivalent computer generated model in an IVE. The IVE model of the brain will replicate the plastic model and will be developed on the basis of photography and laser scanning of the plastic model pieces.

The immersive visualisation facilities at the Hull Immersive Visualisation Environment (HIVE), University of Hull will be used for this project.

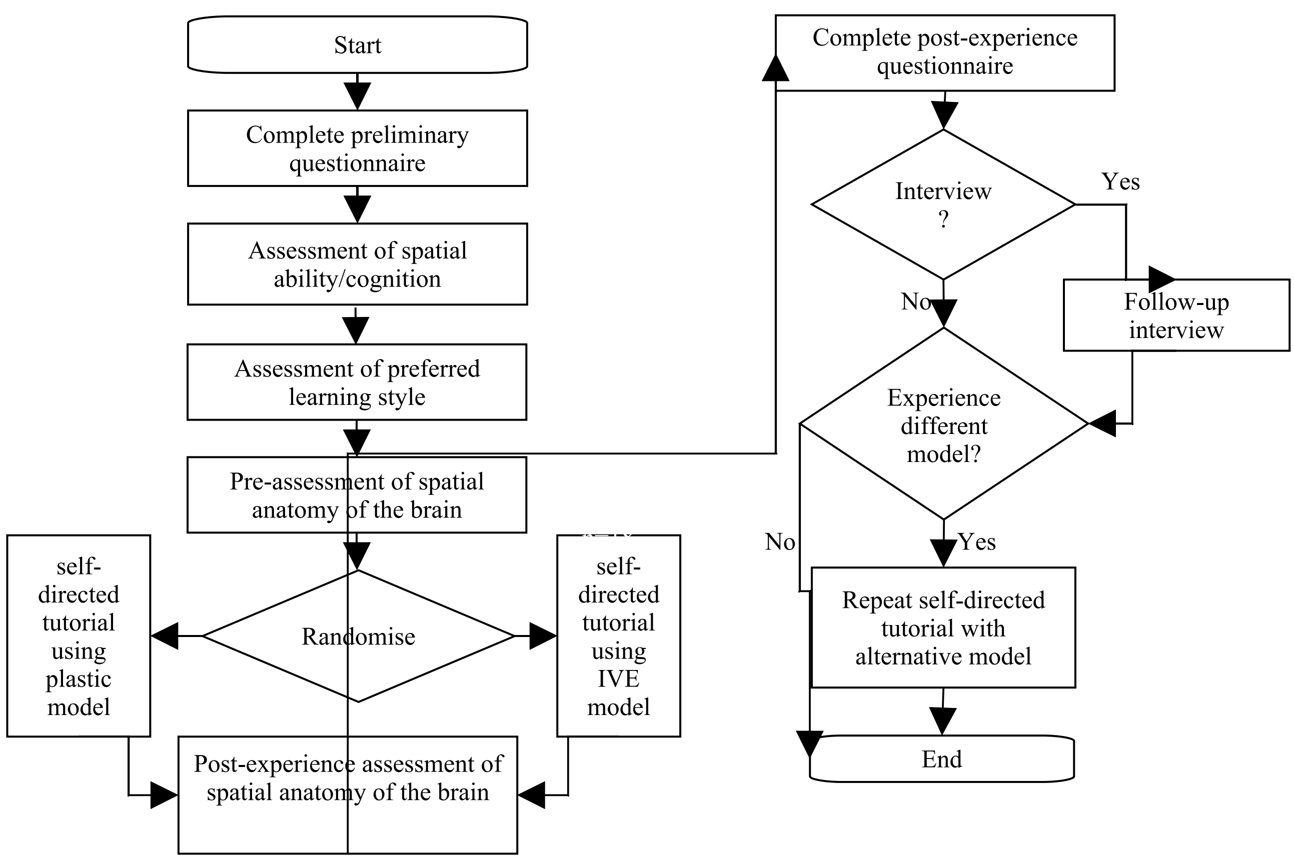
The flowchart overleaf summarises the proposed study design.

Pilot Study
A pilot study using students (n=35) from the host institution and employing a simplified computer model of the brain has recently been undertaken (Appleyard et al. 2006) to allow for determination of adequate sample size, refinement of the self-directed tutorial, MCQ assessments and the questionnaires. This pilot study was funded (£4000) by the host institution (SHU) through the award of an LTA fellowship.

Although the pilot study did not demonstrate a statistically significant difference between the groups in terms of knowledge improvement (p=0.11) the results did show some promising trends that need to be evaluated in a larger study. Mean knowledge improvement in the IVE group (1.72 1.36) was approximately double that of the control group (0.82 1.74). Student views in relation to enjoyment, ease of use, and enhancement of knowledge/visualisation were all significantly better in the IVE group (p<0.001 in all cases). Gender, age, preferred learning style and spatial ability were not correlated with knowledge improvement but baseline spatial anatomical knowledge in the control group was (r=-0.56, p<0.02). The pilot highlighted some minor limitations in methodology that will be addressed in order to further strengthen reliability and validity.

Sample and exclusion criteria
Pre-registration students from radiography and other healthcare programmes at the host institution will be invited to participate. A power calculation following the pilot study suggested a sample size of 52 students per arm of the study.

Study Design



Phase 1 of the study
Pre and post self-assessment questionnaires will facilitate assessment of any differences in students' anatomical knowledge and perceived ability to construct a 3D mental map as well as eliciting initial views regarding the ease of use, enjoyment and perceived benefits of the application. Prior to the self-directed tutorial data on the students' baseline characteristics (see RQ5) will also be collected. Spatial ability/cognition will be assessed using a Lego block test developed on work described by Waywell and Bogg (1999). The test for learning style will be determined following an evaluation of Coffield et al's (2004) assessment of learning style models.

To ensure both groups are matched in terms of pre-intervention knowledge, students will complete a MCQ examination that assesses their knowledge of relational anatomy of the brain and ability to construct a 3D mental map of the structure. This examination has been developed using a method for testing anatomical spatial ability similar to that described by Garg et al. (1999 and 2001). This uses 'rods' intersecting structures in unusual views that require students to indicate the particular anatomical features being intersected or a 'beams eye view' that covers the external parts of a structure and require students to indicate what is being 'irradiated' beneath.

Following the self-directed tutorial each student will complete the same MCQ examination (albeit with questions in a different order). Students' scores for each group will be compared. The effects of random guessing in all MCQ examinations will be minimised by incorporating 'confidence assessment' similar to the scheme described by Gardner-Medwin (1995) and used on medical students. This approach requires students to assign a confidence level to each answer to reflect their degree of certainty.

The Lego Block test, learning style indicators and the main outcome measure (the MCQ examination) will be tested for reliability prior to use. A test, re-test approach will be employed. The pre and post self-assessment questionnaires will employ Likert scales and internal consistency of these will be assessed using a Cronbach Alpha.

Quantitative analysis
Following initial descriptive data analysis and testing for normality a number of further tests will be conducted. Baseline characteristics in each randomised group will be tested for equality using an independent t-test for continuous data and a chi-square test for nominal data.

An independent t-test will be used to compare differences in pre and post intervention MCQ examination scores for each intervention in order to assess any improvement in spatial cognition. Any data for students who do not complete the tutorial (for whatever reason) will be ignored in this analysis. A further independent t-test will be used to compare differences in post MCQ examination scores only for each intervention. This analysis will be undertaken on an 'intention to treat' basis as discussed by Dallal (1998) in order to assess the overall 'value' of the IVE model as a learning and teaching strategy. Post intervention scores will be included in this analysis regardless of whether students completed the tutorial or not.

Differences in the learning experiences (post questionnaire) for each group will be assessed using an independent t-test for continuous data and a chi-square test for nominal data.

Correlation analysis will be used to assess the relationship between spatial ability, preferred learning style and personal characteristics on MCQ scores. This data will be used to inform linear regression analysis. The linear regression will identify the impact of the IVE on the main outcome measure (post-intervention MCQ score) controlling for any characteristic identified as influential in the correlation analysis.

Microsoft Excel and SPSS will be used to analyse the data.

Phase 2 of the study
As limited data exists on how students learn in IVE's an interpretive design will be utilised. A Grounded Theory approach within the Glazer tradition is considered most appropriate. Follow up unstructured interviews will explore and establish the process that the students followed under

the different interventions. Evaluation of the transcribed interviews will be undertaken in order to try to develop a model of how best to support students in enhancing their spatial cognition of brain anatomy. The Grounded Theory approach should ensure this model is grounded in the data developed from the study participants.

Qualitative Analysis

Individual one to one unstructured interviews will be held with consenting individuals. While participants will be asked to volunteer for the interview phase the sampling will be purposive and subjects maybe identified on the basis of particular comments made on the post-intervention questionnaire they complete regarding their learning experience in phase I of the study and/or observation of their participation in the self-directed tutorial. This sampling strategy is designed to allow access to a range of experiences and perspectives; so while volunteers will be requested to consent to participate, specific individuals with different levels of experience within the original sample will be actively sought to add depth and understanding to how learning differs in an IVE compared with traditional environments. Sampling will continue until the point of saturation (that is until no new themes are identified within the interviews). Within later interviews initial themes will be tested to ensure validity of the data and the developing model. A number of strategies will be implemented throughout the interview phase to enhance the quality of the research outcomes. The period of data collection will be prolonged to ensure sufficient time for reading and reflection between interviews. Member checking will be used to verify themes identified through transcribed interviews. Peer-debriefing will be employed to ensure interpretations of the data are appropriate, and a personal journal will be kept throughout the interview period to provide an audit trail of the decision-making process. Interviews will be transcribed rapidly following the interview and read close to the date of the interview so that the essence of the interview can be easily recalled.

Ethical Considerations

Student participation in the study will be voluntary and they will be given an information sheet prior to the study. All data will be anonymised.

All participants study the anatomy of the central nervous system as part of their validated degree programme. This research will not influence this aspect of the curriculum or detrimentally affect their learning in any way.

Previous research (e.g. Bridge et al. 2006) has indicated that a very small minority may experience some feelings of nausea and disorientation whilst using IVE's. To ensure the safety of participants all subjects will be offered the option to stop participating if they experience any adverse effects. However, these students will still be invited to participate in the follow up interviews.

In order to avoid the possibility of one group of students being disadvantaged in the event of one method being significantly better than the other all students will be offered the opportunity to experience the alternative methods post testing.

The pilot study (Appleyard et al. 2006) was approved by Sheffield Hallam University's Faculty of Health and Wellbeing Research Ethics Committee. Further ethics approval will be sought prior to the main study.

Outcomes

1. An immersive, fully interactive computer model of the brain.
2. Enhancement of student radiographers' 3D anatomical knowledge.
3. A clear understanding of the role of immersive VR technology for enhancing radiography students' knowledge of anatomy.

4. The findings will provide new insights into curriculum design for radiography programmes, will direct educational policy and ensure good use of resources in educational settings.
5. Appreciation of the wider potential of immersive VR technology in healthcare education.
6. Material for PhD thesis.
7. Publications (see below)

Timetable

See Gantt chart that follows reference list.

Evaluation strategy

1. Peer review and expert judgment. This research constitutes a PhD programme of study being undertaken by the applicant. Ongoing review by the supervisory team and graduate studies team as well as opinion and recommendations sought from other experts specific to this field is at the heart of this research's evaluation strategy and will ensure quality.
2. Post-intervention questionnaires as described in phase 1 of the study above. These will elicit the students' initial views regarding the ease of use, enjoyment and perceived benefits of the application.
3. Follow-up interviews as described in phase 2 of the study above. These will explore and establish the student experience for the different interventions. Evaluation of the transcribed interviews will be undertaken in order to try to develop a model of how best to support students in enhancing their spatial cognition of anatomy. Member-checking and peer debriefing will further enhance quality of the research outcomes.
4. Peer review of work submitted for publication and formal/informal feedback and evaluation following conference presentation.

Dissemination strategy

1. Interim reports to CoR, host institution (SHU) and partner institution (HIVE)
2. Presentation at relevant conferences including CoR annual conference, ESTRO and Medicine Meets Virtual Reality (the premier conference on emerging technologies for medical care and education)
3. Contribution to PhD thesis
4. Final report available on SoR website
5. Publications in relevant journals to include 'Computers and Education' and 'Radiography'. It is envisaged that work intended for publication in journals such as 'Computers and Education' will focus on the design of the application and wider educational implications whilst work intended for publication in 'Radiography' will focus on the educational implications for radiography more specifically.

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