INVESTIGATING FORMATIVE AND SUMMATIVE ASSESSMENT METHODS FOR TECHNOLOGY ENHANCED LEARNING OF DENTAL CLINICAL SKILLS

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Abstract

The purpose of the research reported in this paper was to use the virtual learning haptic environment designed and evaluated by the hapTEL[1] project to measure students' performance of a range of clinical caries removal tasks and how the feedback they receive from the system contributes to formative assessment in the undergraduate dental curriculum. Twelve VRS workstations were developed by the hapTEL project (Cox et al., 2009) and used for training hand-eye coordination in performing tasks related to clinical surgery replicating the sense of sound, vision and touch. In 2009/10, 144 first-year dental undergraduate students used the first curriculum version of these hapTEL workstations and traditional dental simulators in the phantom head laboratory. A range of evaluation techniques have been deployed by the hapTEL project which include the capture of computer operations based on dynamic screen replays and system logs representing students' haptic interaction with the systems. The visualisations of these logs were analysed to find out how these data could be used to enhance formative feedback techniques and how graphical displays of these operations could improve the quality of traditional teaching methods. The results show that computer log-files collected from haptic dental work stations can be used to display a graphical representation of students' performances. This type of feedback provides immediate evidence to the students of how well they have performed the cavity preparations and how their performances can be improved with multiple attempts. This compares favourably with the less systematic feedback which is possible in the traditional phantom head laboratory because of the limited number of tutors available. These forms of visualisation of the data could therefore be used to

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enhance traditional formative and summative assessment techniques in the dental curriculum.

Introduction

The growth of Information Technology (IT) and Information and Communication Technology (ICT) in higher education (HE) has led to an expanse of technology enhanced learning (TEL) within courses at university level, many of these using IT-based resources such as on-line Virtual Learning Environments (VLEs), computer simulations and video and audio conferencing (McGill & Hobbs, 2007). There is also an increasing use of IT in the area of assessment in HE. Although there is significant research into the advantages of formative assessment (Webb & Cox, 2004) much of this is with children in schools and there is relatively little evidence of the strengths and weaknesses of different formative and summative methods used in HE. Formative assessment is essentially regarded as a qualitative exercise providing a feedback process to the learner, engaging learners and teachers in acquiring a common understanding of what has been understood and helping the teacher to modify their teaching to take account of what has been learnt (Black & William, 1998). Using traditional methods, formative assessment in HE includes providing feedback to individual students during a clinical session amongst the students themselves, between tutor and student. Students are challenged to answer relevant questions.

According to Buchannan (2001), the usage of computer simulators can improve students' learning in dental education. Furthermore, Eaton et al. (2008) show that devices with haptics features simulating the tasks, which are traditionally taught using phantom head laboratory stations, with feedback of sound, colour change, rotation speed, torque, hand-piece vibration, and orientation can be advantageous. They believe that TEL should become ubiquitous, with no distinction between modes of delivery. With the assistance of rapidly advancing technology, Virtual Reality Simulators (VRS) have become integrated into various educational settings including dental education within HE.

Dynamic replays and visualisations based on computer logs of users' inputs and interactions can be effective techniques for studying how one learns from a system (Cox, 2007). Although these techniques have the potential to enhance pedagogical practices when teaching with e.g., haptic technologies, the use of these techniques and their value to learning are still under-researched (e.g., Minogue & Jones, 2005).

Determining whether new technologies, such as those using haptics and other senses, can either provide positive teaching and learning interactions or not, can be challenging. Whilst it is possible to gather tutors' and students' feedback through, e.g., surveys, observations and interviews, other indications of positive learning interactions may not be gathered using only these methods (Sheard et al., 2003). For example, in surgical simulations, specifically in dentistry, it can be difficult to synthesise students' performance with the simulation when a large number of students are involved and a large number of virtual surgical operations are performed.

The purpose of this research is to evaluate the impact of a haptically-enhanced VRS system (in this paper, for simplicity VRS is used) on students' learning through formative feedback.

Curriculum Context of the Study

At King's College London and in many other dental schools, traditionally dental students working on the mannequin head systems in the Phantom Head laboratory receive feedback from other students (peer feedback), tutors, and by observing their own performance using the end result (i.e., the tooth with a prepared cavity). In the VRS system students receive feedback from tutors as well as through peer feedback when working in pairs, but in addition, they receive feedback from the system identifying in a quantitative way how well they have performed the cavity preparation. The hapTEL system can produce a log-file to show the percentage of each layer of the tooth that is extracted and the percentage remained from each layer. This log-file can also show how many times grossly excessive tissue has been removed.

In the traditional method the tutors cannot monitor all students' performances while they carry out the tasks because often there are many students being taught by one or a few tutors. However, in the VRS system feedback of the performance is immediate on screen for each student and the procedures, which individual students have used, can also be replayed for students and tutors showing how well the students have performed the tasks and any mistakes.

The assessment of performance can be approached in two ways:

- mechanistic clinical approach
- biological clinical approach.

The mechanistic clinical approach involves assessing manual dexterity, visual perception, correct angle of holding the drill hand piece (drill), correct movement of the hand piece, and maximum extraction of dental caries and minimum extraction of healthy tissues (enamel and dentine), no pulpal exposure, usage of turbine hand piece at the start and slow-speed hand piece when reaching closer to the extremities of the cavity, and hand-eye coordination. In the biological clinical approach, students are expected to acknowledge all the clinical conditions of the teeth of the virtual patient and identify the limitations of possible treatment and then act accordingly.

The VRS system's replay facility can assist dental tutors to assess a student's performance and judgements. The additional opportunity for feedback therefore not only potentially enhances the students' learning experience it provides real evidence regarding the individual's development and information for preparation toward the summative assessment.

This research focuses on analysing students' haptic operations and exploring further how visualisations of these operations can improve the quality of traditional teaching methods.

Research Aim and Objectives

The aim of this research is to investigate and evaluate the impact of the integration of a Virtual Reality Simulator system, hapTEL, on students' learning and how this system could also be incorporated into the conventional assessment procedures within the dental curriculum.

This research is based on the growing need to investigate the integration of new technologies into the training received by dental students. Assessment is at the core of higher education courses and in particular dental education to ensure the requisite standards of competence and safety set by the UK's General Dental Council (GDC) are met. For the purpose of this paper, the objective is to investigate the usage of computer log-files as formative feedback to enhance the learning process for undergraduate dental students, by transferring the log-files to graphical representation.

Materials and Methods

Twelve VRS workstations were developed by the hapTEL project (Cox et al., 2009) and used for training hand-eye coordination in performing tasks related to clinical surgery replicating the sense of sound, vision and touch.

In 2009, 144 first-year dental undergraduate students used the first curriculum version of these hapTEL workstations and traditional dental simulators in the phantom head laboratory. A range of evaluation techniques have been deployed which include the capture of computer operations based on dynamic screen replays and system logs representing students' haptic interaction with the systems. The students' haptic interactions were captured as computer logs, and the visualisations of these logs were analysed to find out how these data could be used to enhance formative feedback techniques and how graphical displays of these operations could improve the quality of traditional teaching methods. The hypothesis is that these representations might be used to support face-to-face formative tutor feedback systems used in the laboratory.

Out of 144 Year 1 undergraduate dental students, 46 were randomly assigned to use the hapTEL system. As per the course programme arrangements and due to the limited number of stations, these 46 students were divided into two groups. Each group worked in pairs using the 12 hapTEL systems alternating weekly. In the hapTEL system, the number of tetrahedrons represents the total volume of virtual tooth material. The task involved removing artificial decayed tooth material (e.g., represented in brown coloured tetrahedrons) whilst carefully avoiding removing the healthy parts of the tooth, i.e., enamel (off-white coloured tetrahedron) and dentine (ivory coloured tetrahedron) around the boundaries of the decayed part and also avoiding hitting and removing the dental pulp (red coloured tetrahedrons). There were three tasks (plus a trial task) with varying difficulties (the tasks became more difficult progressively from Task 1 to Task 4 — Task 1 being the trial task and Task 2, 3, and 4 represented as Task A, B, and C in the following section) according to how close the decay is to the pulp and the shape and size of the decay. For each task, the students could make as many attempts as they wished within the average time given of about 45 minutes. The computer logs recorded represent the total amount of tetrahedrons for each of the virtual tooth parts, the amount of tetrahedrons removed, the location of tetrahedrons, and the time spent in each attempt.

Forms of Data Display

The interaction between a VRS station and one student (FH2A[2]) has been analysed and graphically displayed in this section. The following data shown in Table 1 are illustrative examples of the kinds of recorded operations provided by the system. In this table one student's performance is shown for three different cavity preparation tasks (A, B and C); the data being obtained from the log-files saved on the computer as part of the VRS work station.

The data shown in Table 1 provides formative feedback enabling the students to detect automatically, for example: the average time taken for each task, the number of attempts, number of times they have exposed the pulp, etc. This can then be analysed by the teachers to see how a student progresses in completing each task. Task A required the student to remove a class 1 caries in a single tooth (shallow carious lesion through enamel in a haptic tooth); Task B involved the student removing caries from a haptic tooth located in a non-haptic lower jaw

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[2] According the convention used for identifying the participants, this particular student is from hapTEL group (H), has been working on station F, second operator (2) for that specific session and h/she is from group A (group A and B were alternating groups for each week).

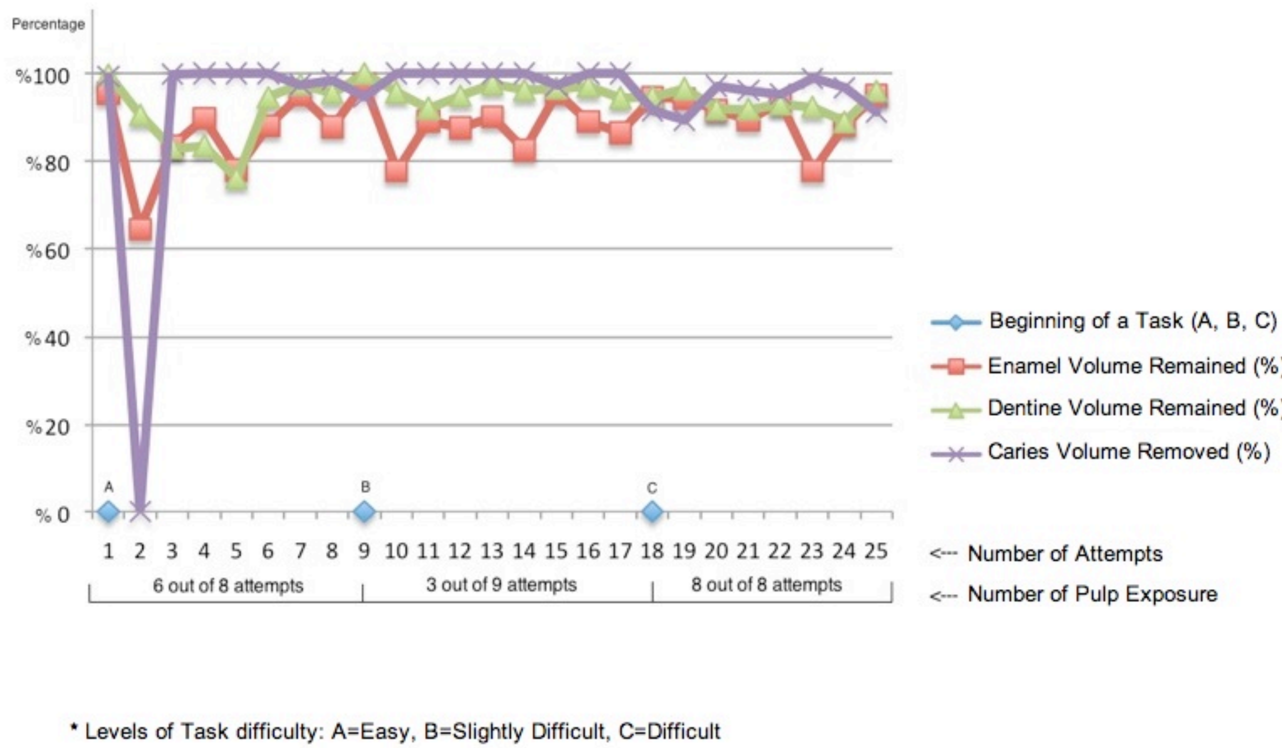
(carious lesion is through enamel and dentine) and Task C involved the student removing a cruciated caries from a haptic tooth located in a non-haptic lower jaw (carious lesion is near the pulp). In Table 1, Task C was clearly the most difficult task for the student FH2A based on the number of attempts and number of times that the pulp was exposed. Although the system calculates the volume of the pulp exposed (in tetrahedrons) in the fifth column (with the heading "Pulp Exposure") it is only shown if the pulp has been exposed or not. This is because for assessment it is more important that students learn to avoid exposing the pulp at all.

Table 1: Logs Representing a Student's (FH2A) Dental Operations with Haptics

Task	Enamel Remained(%)	Dentine Remained (%)	Caries Removed (%)	Pulp Exposure	Performance Time (minutes)
A	95.5	99.68	99.3	None	18.35
	64.4	90.54	0	Exposed	6.01
	83.47	83.03	99.83	Exposed	4.01
	89.74	83.54	100	Exposed	3.73
	77.94	76.12	100	Exposed	5.45
	87.99	94.52	100	None	1.8
	95.1	97.49	97.46	Exposed	2.48
	87.77	95.54	98.51	Exposed	2.41
B	97.68	99.96	94.58	None	2.14
	77.72	95.75	100	None	6.39
	89.14	92.06	100	Exposed	2.56
	87.54	94.91	100	Exposed	1.7
	90.08	97.66	100	None	2.27
	82.45	96.19	100	None	4.14
	95.45	96.62	97.25	None	1.03
	89	97.04	100	Exposed	3.11
	86.43	94.44	100	None	1.93
C	94.44	94.76	91.41	Exposed	2.75
	94.21	96.57	89.38	Exposed	1.84
	91.59	91.85	97.12	Exposed	2.69
	89.31	91.84	96.11	Exposed	2.23
	93.41	92.95	95.29	Exposed	1.95
	77.75	92.34	98.81	Exposed	5.99
	88.15	88.93	96.69	Exposed	2.5
	94.94	95.98	91.13	Exposed	1.61

In order to visualise and to zoom into the details of an operation, the data in Table 1 can be transformed into Figure 1. Here a student can easily see which one of the attempts in a task is the most successful indicated by the low amount of healthy tissue removed and low amount of decayed tissue remaining.

Figure 1: FH2A's Operations for Task A, B and C



Whilst Table 1 shows one of the student's operations, from these attempts, it is noticeable that the student performance could be considered as "improving" as the tasks became more difficult from task A to task C. In Figure 1, under the horizontal axis, the number of pulp exposures occurred performing each task is shown. For example within Task B, the pulp was the exposed in three attempts out of nine.

Discussion

The evidence above shows that computer log-files which were collected from twelve VRS stations can be used to display a graphical representation of students' performances. As an example in this paper, one student's data record was displayed graphically. This graphical representation can provide feedback for students and their tutors while they perform the tasks. This feedback form can be part of a student's self- and peer assessments. These forms of visualisation of the data not only can be used as part of formative assessments but also summative assessments.

Using these forms of visualisation, students' interactions with VRS systems can be analysed and compared in different forms as follows:

- Within task — single student: each of the student's progress within each task by inspecting the logs of every attempt, comparing one to another.
- Within task — between students: the overall progress of all students for each task.
- Between task — single students: each student's progress across the three tasks.
- Between tasks — between students: the overall progress of all the students across all three tasks.

All of the illustrative examples above show how automatic capture of haptic operations and their visualisations can provide indications of learning. However, careful interpretation of analysis of these data must be considered. For example, when large amounts of decayed material remain as indicated by the logs, this may also mean that the student had just decided to restart the operation without finishing the attempt. Therefore, it is important to triangulate this finding with other sources of information, i.e., surveys, interviews, and, in particular, observations.

Further investigation is also needed to understand how these tools are going to impact on the kinds of formative feedback given by tutors and the kinds of learning interactions that students experience when feedback is given automatically or on demand. Also, the results presented can be compared with the students' performance in removing decayed material using a traditional dental simulator with plastic teeth.

There is a growing consensus in the literature that greater use of technology and its integration in HE is advantageous for all the stakeholders. This trend started with the integration of IT and ICT into different educational settings especially in HE. As technology evolved the World Wide Web (the Internet) has become more established, the computer interface designs have matured, and computer and Internet access has become wide-spread. To have a better understanding about the integration of technology in training dental students, empirical work was carried out involving collecting data including dialogue between tutors and students while using the conventional (mannequin) lab and technologically enhanced (hapTEL) lab. Data collection involved video recording (Heath et al., 2010; Hyland, 2011), feedback forms, which will be triangulated with interviews and the log-files collected by computers (instant feedback through computer interface) in the hapTEL lab. In this paper one form of visualisation of log-files has been illustrated. Analysis of recorded videos and feedback forms are currently in progress.

The participants of this study had the advantage of using modern technology replicating the real tooth environment while receiving instant feedback from the VRS system and their tutors. As mentioned above, both lab activities were video recorded and all the computer log-files have been collected from the VRS systems. Future analysis can use all these data as part of the empirical studies investigating advantages and disadvantages of the use of VRS systems combined with conventional systems, and their integration in the assessment of dental education. It can be predicted that as much as dental education can benefit from the advantages of integration of VRS systems especially in assessment (e.g., objectivity, accuracy, instant feedback, less cost), these advantages cannot outweigh the benefits of tutors giving personal feedback, assessing the level of students' understanding, and explaining the rationale for the method used for each task. More investigation is needed to explore to what extent VRS systems can be integrated to be part of formative assessment and summative assessment of the dental curriculum.

Feedback in the form of visual, tactile sensation (touch) and sound (of the drill) can be part of the formative assessment enhanced by the VRS systems. Experienced tutors can also monitor students' progress while using these systems. One of the advantages is that learners can repeat the task as many times as necessary and it is more cost effective compared to the traditional mannequin lab.

It is understood that feedback in different forms of tutor-students and student-student (peer) can be important elements of formative assessment. Returning to address this important point, we emphasise that as an added benefit of technological integration in dental education, extra feedback through different features of the computer interface can be enhance the range of feedback provided to students and thereby enrich the learning experiences.

The integration of technological enhanced systems into medical educational settings could be considered as complementary to the conventional system. At the beginning of the dental programmes (e.g., Bachelor of Dental Surgery) the VRS systems could be used for introduction and more practice with lower cost and more accessibility compared to the conventional systems. Also students could benefit from technology by practising more with no limitation on the number of teeth. Diagnostic and formative assessments could therefore be enhanced by rigorous feedback using new computer technologies.

Conclusions

This investigation supports the findings by Buchannan (2001) and Eaton et al. (2008) that VRS can enhance dental students' learning as well as the assessment procedures with features such as graphical visualisation, video recording and replaying, graphical user interfaces, and head tracking through vision, sound and haptic feedbacks of the system. As technology develops there will be new learning environments that are evolving, liberating and immersive, which could stimulate creativity of the learners and assist course designers in producing innovative learning and teaching in dental clinical practice. The research reported in this paper supports the claims made by Minogue and Jones (2006) that the development and testing of haptic interfaces incorporating several points of contact to facilitate optimal acquisition of tactile feedback as well as development of simulating sound and vision in VRS can enhance teaching and learning. The captured data by the computer system can be transformed into different representations, which can then be analysed for interaction patterns and anomalies. Moreover, these representations can be used to support face-to-face formative feedback systems used in the classroom.

The empirical work carried out with this investigation shows that VRS systems can provide more accurate feedback interfaces through sound, vision and touch by which the students' improvement in clinical skills can be monitored as part of their diagnostic, formative and summative assessments.

The hapTEL project is currently analysing a wide range of other data to understand how students perceive, process, store, and use haptic, optic, and sound information, and to what extent these findings can enhance the teaching and learning in dental education.

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