Innovations in Teaching and Learning Strategies to Improve the Effectiveness of Using Haptic Simulators in Higher Education for Dental Students and Other Health Care Disciplines

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Abstract: This paper briefly reviews the teaching and assessment strategies developed over ten years of trials with over 1200 undergraduate students to make effective use of virtual haptic simulators in higher education disciplines such as dentistry and nursing. In the last five years (2012-17) these strategies have evolved to include a range of technology enhanced learning resources (TEL) in a blended learning setting to assess the performance progression of students' learning cavity preparation skills. Every students' performance outcomes were retrieved from the hapTEL simulator log files for each task including the percentage of caries, healthy tissue and pulp removed. The use of a blend of video recorded short lectures followed by face to face teaching, pair working, haptic, visual images and sound feedback, and individual student assessment record keeping showed an improved reliability in performance of the work-stations and a consistently higher rate of student's log files records compared with previous years. Records of students' performance collected over two years showed that the HapTEL system enabled students to perform better at cavity preparation after practising over two sessions.

Keywords: Higher Education; Dental Education, Haptic Simulators, Technology Enhanced Learning, Clinical Skills, Curriculum Innovation, Assessment Techniques, Healthcare Professions, Blended Learning.

1. Background

Haptics means the sense of touch and involves the science of incorporating this and the interaction with the external environment through touch. As a tool for teaching and learning it is one example of Technology Enhanced Learning (TEL) which is particularly useful for the teaching of skills involving touch control and hand-eye coordination in the different healthcare disciplines in higher education (HE) [1-3]. The growth of computer technology and increasing use of TEL in all sectors of education have led to changes in the delivery of courses which can transform the way that some schools, colleges and universities support teaching and learning [4, 5].

There have been many previous studies reporting on the various benefits of using haptic simulators in dental and medical education which support curriculum innovation and development in university teaching and learning [6-8]. Furthermore,

previous longitudinal studies into the impact of the use of the hapTEL simulator on students' learning have shown that students taught in Year 1 of the Dental undergraduate programme using only the hapTEL simulator achieved similar accuracy compared with those taught traditionally when assessed at the end of the course sessions [9]. Measurements of the effects of using haptics on students' psychometric skills, which are important skills for health care professionals, also showed improvements over time from using the hapTEL simulators (ibid.). Other studies have also shown that different haptic simulators can enhance students' learning of clinical skills in different curriculum settings [10] and have a positive impact on their skills development over time [11]. This body of evidence has led to growing expectations that traditional learning and teaching systems will need to adapt and change in universities in order to keep up with students' expectations and benefit from the opportunities which TEL can offer to teaching and learning [12, 5].

However, in spite of this growing body of evidence, haptic and other technologies are often not easily adapted into the HE curriculum because of insufficient understanding of how they can best be integrated into courses and individual sessions. Entwistle [13], in 1987, identified a range of institutional, epistemological and pedagogical influences of the quality of learning achieved from an analysis of a wide range of research studies into the impact of innovative teaching on HE students' learning shown in Fig.1. By using this model, Entwistle, Nisbet and Bromage [14] demonstrated how this conceptual framework can be used to identify the important influences on using an innovation and its impact on students' learning experiences and to map the data collected from a range of methods to various aspects likely to influence the quality of learning achieved within the conceptual model.

We can see from this framework that any contribution to students' learning of haptic simulators or traditional phantom head simulators or any innovation in HE will depend amongst other influences upon the students' perceptions of the teaching-learning environment, how the course content is selected, organized, presented and assessed, how the teaching-learning environment is designed and implemented and so on.

Previous studies of the haptic system discussed above have focused on the impact on students' learning and attitudes and the integration into the curriculum [2, 8, 9]; the focus of this paper therefore is on how the teaching and learning environment has been designed and revised from when the systems were first used in 2008 to the present day, and what teaching strategies and assessment techniques have produced the most consistent improvement and measures of students' learning progression.
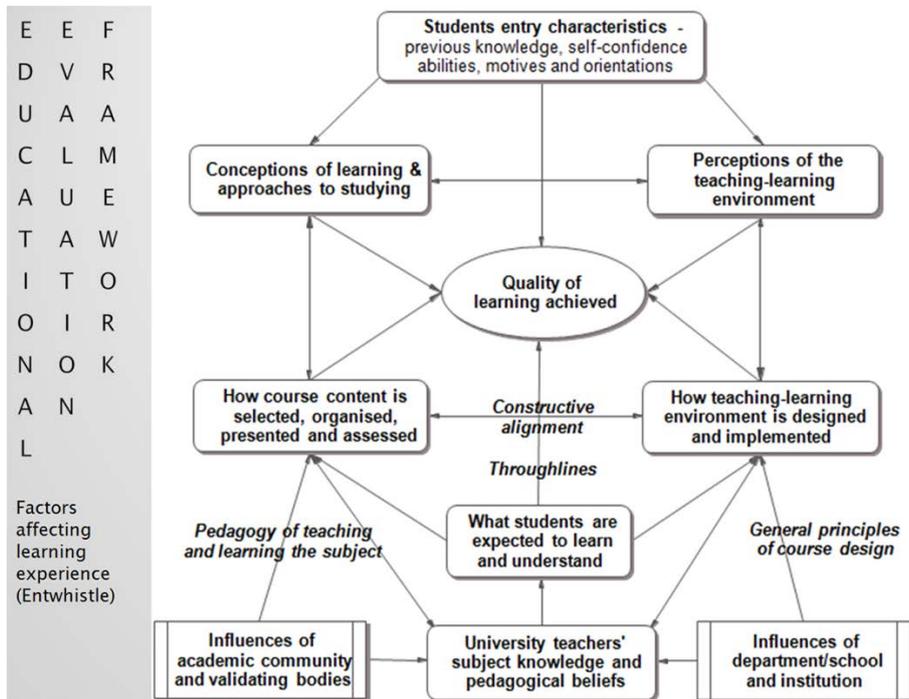
Fig. 1 A model of the teaching-learning process in higher education. (Entwistle, 1987)

2. Introduction to the study

In order to address the range of factors identified by Entwistle [13] the approach taken by the hapTEL project for the development of the system is shown in Figure 2 involving an iterative development process between the technological development, curriculum innovation and integration and educational evaluation. This framework represents the links between the three elements of a robust strategy for developing and evaluating a Virtual Simulator or any other innovation in education.
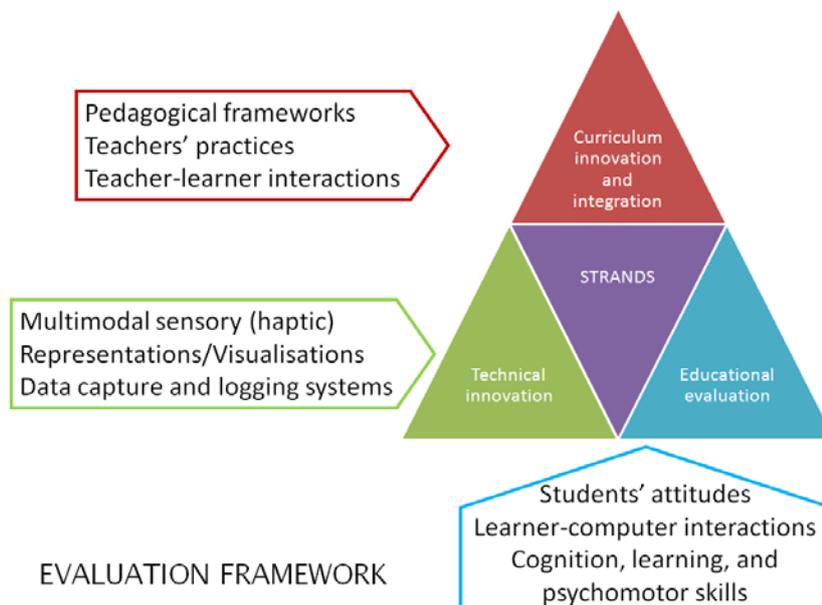
Fig 2 Development and Evaluation Framework for the hapTEL system

3. Development of the hapTEL Virtual Simulator

The virtual hapTEL simulator, shown in Figure 3 below, was developed iteratively from 2007. Following a series of upgrades and modifications resulting from extensive student and teacher evaluations, twelve curriculum systems were installed in the hapTEL teaching laboratory in September 2008. Further minor improvements were made consequent to each year's undergraduate student use. The haptic work-station consists of a haptically-enabled modified dental drill (or in the case of teaching injections to nursing students, a syringe) providing realistic force-feedback to the operator/learner during use within the virtual clinical environment. For the dental students, this environment, which includes a set of teeth in a jaw and the dental drill, is displayed on a 3D dual-screen system viewed by the operator using 3D glasses (Fig. 3). A camera which tracks the movement of the student's head provides colocation of the image with the student's position so that the student can move his or her head around the mouth to get the best view as in real life. The virtual hand-piece (shown on the screen) is operated by the student holding the real drill. The speed of the drill can be pre-selected by the student and the power is controlled using the foot pedal.

Learners can select from a choice of scenarios and complexities which generally involve a decayed cavity lesion requiring excavation. The system is set up to log raw data of each attempt and feeds back information such as the amount (%) of decay, enamel, dentine and pulp removed at the end of the attempt. Users can replay their attempts on the screen to assess and learn from their performance.

382
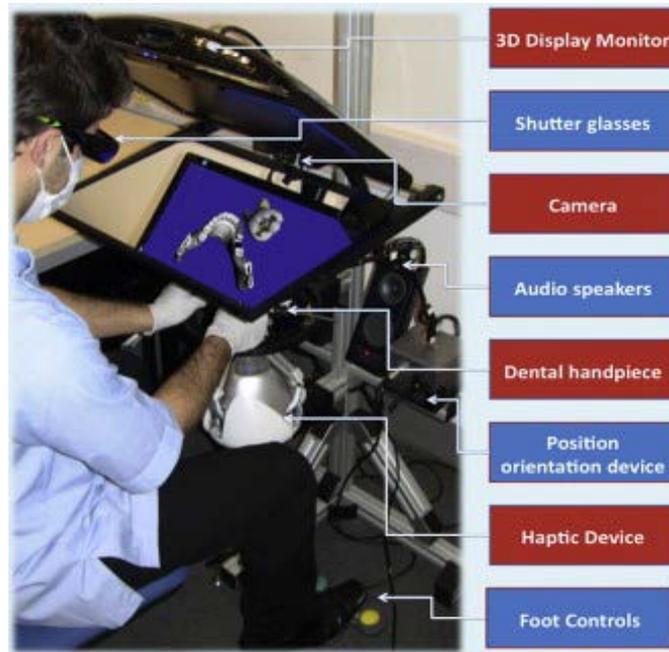
Fig 3 hapTEL Curriculum Dental Simulator

The priorities regarding the design of the curriculum version were to develop a system which:

- was as close in design as possible to the 77 traditional phantom head dental chairs which the students would also be using;
- would have a large enough display so that pairs of students and supervising tutors could see the simulated mouth on which the student was working;
- would be cheap enough to enable the project to have 12 identical functioning systems from the start of the student trials;
- would be robust enough to require minimum maintenance;
- could be used by students working in pairs as 'dentist' and 'dental nurse';
- would store all the actions of the students including video playback so the students, researchers and tutors could monitor and review the students' work;
- would store all the achievement scores of the students such as percentage of decayed tissue removed, healthy tissue remaining and whether or not the pulp had been exposed.

4.   Evolvement of the Teaching and Learning Setting and Workshop Activities

From the incorporation of the curriculum version of the hapTEL system into the undergraduate dental curriculum in October 2008, the teaching and learning settings

have changed as a consequence of yearly evaluations of the range of issues previously identified by Entwistle [13] and previous project results reported in Section 1 (e.g. see Shahriari-Rad [9]). Figure 4 below shows the tutor demonstrating to the pair of students how to use the work-stations which was part of the teaching approach for every year of the study. However, many other aspects of the blended learning environment have changed to prevent the malfunctions of the system and to improve the confidence of the students to take charge of the learning activity.

Fig 4 Tutor instructing students in the hapTEL virtual laboratory

Table 1 below shows the teaching and learning settings and strategies used in the hapTEL laboratory over the last nine years showing how the organisation and assessment procedures have changed as a result of yearly evaluations and staff and student feedback. During the first four years of the project there were 12 complete machines available for use by 24 students per session in parallel with the rest of the year's cohort (98 students) working in the traditional 'Phantom Head' Laboratory. This enabled a direct comparison to be made between the hapTEL and traditional students' learning experiences, the results of which are discussed in Section 1 above. During this period the hapTEL machines were still under development and were technically unreliable at times requiring the presence and support of a skilled cybernetic technician. As one can see from this table the number of staff required to support the student sessions has reduced from five during 2008-11 to only 2-3 since 2012. This has been possible by providing more training to the students on how to use the machines and by pre-empting possible hiccups through the previous years' experiences which have been addressed in the introductory videos.

In comparison with the traditional laboratory setting in which 70+ students would be working on Phantom Head dental work-stations with only three tutors and two to three technicians present, the support staff for only 12-14 students in the hapTEL lab

is greater. However, in the traditional lab most of the tutor feedback is after a tooth operation has been completed whereas in the hapTEL lab, the system itself provides dynamic immediate feedback on the procedures themselves to every student and additionally the log files of their performances at the end of every operation.

Table 1 Teaching and Learning Setting and Blended Learning Strategies (2008 – 2017)

Year	Teaching and Learning Setting and Blended Learning Strategies
2008-11	1 – hour introductory lecture followed by 24 students working in pairs on the 12 machines in the hapTEL laboratory for 1.5 hours supervised and assisted by a senior clinician, 3 assistant tutors and 1 technician. 3 sessions (4.5 hours) in total. Log file records stored of every student action and task achievement. (see [9], for more details).
2012-14	Introduction to the workshop session by a non-specialist lecturer followed by 12 students working in pairs on the 6 machines in the hapTEL laboratory for 1.5 hours supervised and assisted part of the time by a senior clinician, assistant tutor and TEL support person. 2 sessions (2 hours) in total. Log file records stored of every student action and task achievement.
2014-16	Introduction to the workshop session by a pre-recorded video of Dental specialist lecturer and face-to-face non-specialist lecturer followed by 12 students working in pairs on the 6 machines supervised and assisted part of the time by a senior clinician, assistant tutor and TEL support person. 2 sessions (1.5 and 1 hour respectively). Log file records stored of each student's action and task achievement. Students' individual photos of their log files submitted for assessment by academics.
2017	Same as for 2014-16 but student log-files recorded by the student on individual assessment sheets during the actual sessions and then submitted for assessment.

Following the completion of the research phase of the hapTEL project (2007-11), the machines were then integrated into a revised dental curriculum to take account of the results from the earlier attitude study by Green [15] which had shown that students perceived there to be a greater value in using the hapTEL simulators **before** using the 'phantom head' in order to prepare them for the more complex clinical tasks which the latter required.

During 2012-14, although the hapTEL sessions were now included yearly in the first year of the Dental Undergraduate curriculum (BDS-Year1), the sequence of activities in each first session for a tutor group of students (N=10/12) was a 20 minute introduction given by a lecturer but not always a dental clinician, followed by a 5 minute demonstration on one of the machines, followed by students working in pairs (one as the dentist operating the hand-piece and performing the cavity preparation: and the partner operating as the dental nurse controlling the instrument selection, speed of drill etc.). They would then change places for the second half of the session.

While working on the virtual dental work-stations the students are always required to wear their personal protective clothing (PPE) to familiarise themselves with wearing aprons, gloves and masks in all clinical settings. Additionally, they wore 'shutter' glasses which enable them to see the image in 3-D; and a camera (located

below the screen) tracking their head movements around the haptic jaw moves the image to match their viewing position. The 'show records' option enables the students to see the log files on the screen of the results of their cavity preparation. An example of one student's results for Cavity 2 (a floating tooth with a small carious lesion) is shown in Figure 5 below.
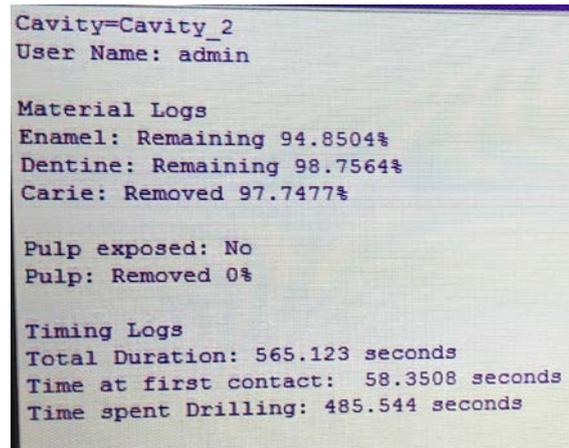


```
Cavity=Cavity_2
User Name: admin

Material Logs
Enamel: Remaining 94.8504%
Dentine: Remaining 98.7564%
Carie: Removed 97.7477%

Pulp exposed: No
Pulp: Removed 0%

Timing Logs
Total Duration: 565.123 seconds
Time at first contact:  58.3508 seconds
Time spent Drilling: 485.544 seconds
```

Fig 5. Student iPhone photo of his log files result for Cavity 2

The log files, displayed in Figure 5, show that the student succeeded in preserving 94.8504% of healthy enamel and 98.7564% of dentine while removing 98.7564% of the caries without exposing the pulp, which is a very good result.

During the sessions held in 2014-16 (see Table 1), once the option to end the drilling procedure had been chosen by the student taking the part of the dentist, then there was no further opportunity to remove more healthy tissue to improve his/her task results. This sometimes resulted in students forgetting to photograph every attempt. Furthermore, not all the students remembered to take photos of their results before swapping over with their partner in spite of repeated reminders. Table 2 below shows the results for a sample of 10 students (out of 121) for the task called Cavity 3 which requires the students to remove as much caries as possible for a tooth located in a lower jaw.

The results in Table 2 show that seven out of ten students exposed the pulp which is to be avoided if possible when working on real patients. However, all ten students managed to remove over 83% of the caries while retaining over 91% of healthy enamel and 96% of dentine which is a good result for Year 1 novice students' first attempts. These detailed individual results are not possible in the traditional Phantom Head Laboratory because the students' performances are only assessed by the end results as observed by the tutor. There is no computed result.

Table 2. Sample of 10 students' log file results for Cavity 3 (tooth in lower jaw) in 2016

			Cavity 3				
% of healthy enamel remaining	% of healthy dentine remaining	% of caries removed	Pulpal exposure	% of pulp removed	Time at first contact - secs.	Time spent drilling - Secs.	Total duration - Secs.
93.00%	99.00%	98.00%	yes	0.50%	17.50	277.96	313.02
91.88%	97.77%	94.30%	yes	0.02%	14.11	99.03	117.71
97.03%	96.99%	91.58%	yes	0.30%	17.81	131.81	159.76
98.34%	96.79%	82.44%	yes	0.72%	218.11	430.44	671.30
96.56%	99.57%	96.77%	no	0.00%	91.48	485.24	581.60
97.91%	98.92%	83.69%	yes	0.61%	146.53	52.19	270.52
96.53%	97.30%	89.61%	yes	0.87%	9.03	203.28	218.39
97.87%	99.75%	94.09%	no	0.00%	11.48	170.26	198.90
96.24%	96.71%	94.44%	yes	0.39%	26.88	102.86	137.29
96.29%	99.81%	96.42%	no	0.00%	31.73	163.89	202.88

In order to improve the students' understanding of the clinical skills and concepts they were aiming to learn, from the previous years' results (up to 2014) we decided to make further changes to the teaching strategies and students' learning activities as follows:

- For the introduction to Session 1, we prepared a series of short videos of a Senior Dental Consultant explaining to all the students the reasons for the activity, the procedures they should follow, how to wear their PPE, work in pairs and how to operate the hapTEL system.
- In addition to demonstrating to the student group in each session, how to start up and operate the hapTEL work-station, a senior TEL expert demonstrated how to trouble shoot the work-stations to remedy regular minor problems (e.g. the system freezing, shutter glasses switching off, drill needing recalibrating) which improved the students' confidence and satisfaction when using the system.
- In order to obtain 100% of the log-file results, this year (February and March, 2017) all students have been issued with an assessment sheet at the beginning of every session on which they have to record every attempt made on every task (cavity) similar to those shown in Table 2. These achievement sheets are then collected at the end of every session and submitted for data entry to the Dental Institute's academic centre.

Table 2 above is one example of many student records to show the detailed feedback which the system can provide to each and every student. Evidence of improvement to their learning has been reported in previous papers as discussed in Section 1. What we have found in this study is that when students are provided with these individual results at the beginning of the second session, they are keen to use them as a starting position for improving their skills and performance further. There is

no traditional or other haptic system currently available which provides this important tool for effective formative assessment in dental education.

5.   Discussion and conclusions

The previous research evidence reviewed in this paper in Section 1, including the analysis of ten years of over 800 students results [9, 16] have shown that the use of haptic simulators do enhance students' learning when used in an *appropriate educational setting*. The hapTEL system provides a dynamic real time feedback to the learner which has been shown by many previous studies into formative assessment that this enhances students' understanding [17, 18]. The study of the various educational settings reported in this paper shows that using haptic simulator enable students to work repeatedly on dental procedures consequently refining and improving their skills with little additional costs such as purchasing plastic teeth.

As discussed above, because the hapTEL system has no incorporated structured lesson plans or goals the additional blended activities have been evaluated throughout the sessions every year over the last 10 years through student feedback, the results of the log-files, the frequency of the systems crashing, the attendance rate for the students, and the speed at which the students can progress through the tasks. It is often assumed by other HE Dental Schools as discussed earlier that the most effective pedagogical approach to using haptic work stations (and other simulators) is to provide all the structured activities and student instructions within the system itself. However, we have found that by providing specific educational objectives through the videos before they start using the systems and by providing the individual assessment sheets and tutorial real-time guidance, the students have been more focused on achieving good outcomes as shown in the example results above and the 100% returns of their log-files.

In conclusion, the evidence presented in this paper shows that the benefits of using virtual reality simulators for dental and other healthcare programmes may significantly advantage students in their learning and in the longer term improve the treatment of patients. It also shows that it is not necessary to have a complete range of features in order for students to benefit from its use. The hapTEL system is much less diverse than the traditional Phantom Head system yet the evidence of 10 years of results from over 1200 students has shown that using it still enhances the learning of the students over just two sessions. What this paper argues is that the educational settings in which these simulated activities occur needs careful planning and timing with additional materials and goals to maximize the educational impact of the experience.

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