Interactive Radiological Anatomy eLearning Solution for First Year Medical Students: Development, Integration, and Impact on Learning

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A technology enhanced learning and teaching (TELT) solution, radiological anatomy (RA) eLearning, composed of a range of identification-based and guided learning activities related to normal and pathological X-ray images, was devised for the Year 1 nervous and locomotor course at the Faculty of Medicine, University of Southampton. Its effectiveness was evaluated using a questionnaire, pre- and post-tests, focus groups, summative assessment, and tracking data. Since introduced in 2009, a total of 781 students have used RA eLearning, and among them 167 Year 1 students in 2011, of whom 116 participated in the evaluation study. Students enjoyed learning (77%) with RA eLearning, found it was easy to use (81%) and actively engaged them in their learning (75%), all of which were associated to the usability, learning design of the TELT solution and its integration in the curriculum; 80% of students reported RA eLearning helped their revision of anatomy and 69% stated that it facilitated their application of anatomy in a clinical context, both of which were associated with the benefits offered by the learning and activities design. At the end of course summative assessment, student knowledge of RA eLearning relevant topics (mean 80%; SD ±16) was significantly better as compared to topics not relevant to RA eLearning (mean 63%; SD ±15) (mean difference 18%; 95% CI 15% to 20%; P < 0.001). A well designed and integrated TELT solution can be an efficient method for facilitating the application, integration, and contextualization of anatomy and radiology to create a blended learning environment. Anat Sci Educ 7: 350–360. © 2013 American Association of Anatomists.

Key words: gross anatomy education; medical education; undergraduate medical education; radiology education; technology-enhanced learning; curriculum integration; e-learning

INTRODUCTION

The application and use of radiology is an integral part of clinical diagnosis and patient management (Mirsadraee et al., 2012). Throughout their future career, medical students will come into contact with radiology as users of imaging services and/or as fundamental skill and competency within their specialty (Mirsadraee et al., 2012). They must acquire a basic understanding of radiology and its use in contemporary medical practice no matter what specialty they progress into. Substantial variation in radiological education exists across
institutions worldwide (Durfee et al., 2003; Kourdioukova et al., 2011a; Lee et al., 2007; Oris et al., 2012). Research suggests the need for a formal radiology curriculum integrated horizontally and vertically within the existing program (Kourdioukova et al., 2011a; Miles, 2005). This is being facilitated by the recent development of radiology curriculum frameworks with defined outcomes-based learning objectives (AMSER, 2012; RCR, 2012; Webb et al., 2013).

Advances in technologies have revolutionized the depiction of human body structure and function using radiological imaging and changed the way medical education is delivered (Miles, 2005; Phillips et al., 2013; Tam et al., 2010). Technology enhanced learning and teaching (TELT) has become integral for the delivery of teaching and learning in medical education, and medical schools are encouraged to “take advantage of new technologies, including simulation, to deliver teaching” (GMC, 2009). The highly visual nature of radiological imaging, combined with the electronic viewing of radiological images in clinical settings, makes TELT an ideal medium for the delivery of contextualized radiology education (Grunewald et al., 2003; Ketelsen et al., 2007; Miles 2005). Research suggests that introducing students to radiology in the early years of the medical curriculum is effective in facilitating the development of an increased interest in and a more positive perception of radiology and providing opportunities for applied contextual teaching and learning of anatomy (Branstetter et al., 2007; Lee et al., 2007; Phillips et al., 2013). Together, the technological advances and trend towards contextual, integrated teaching of radiology from the early years have resulted in a variety of ways in which technologies are utilized for the delivery of radiology teaching and learning within anatomy. Examples include digital radiological images with annotations (Grunewald et al., 2003; Ketelsen et al., 2007), multiplanar viewing and three-dimensional reconstruction (Petersson et al., 2009; Rengier et al., 2009; Tam, 2010), cadaver imaging combined with dissection (Chew et al., 2006; Jacobson et al., 2009; Lufler et al., 2010; May et al., 2013), digital imaging libraries and access to Picture Archiving and Communication Systems (PACS) (Miles, 2005; Turmezei et al., 2009).

At the University of Southampton Faculty of Medicine, early years radiology teaching had historically been incorporated into lectures given by radiologists and anatomists and gross anatomy practical and tutorial sessions facilitated by anatomists in the first 2 years of the systems based 5-year undergraduate Bachelor of Medicine (BM) curriculum. During scheduled practical and tutorial sessions, students completed activities using prosected cadaveric specimens, bones, models, anatomical drawings, clinical links, quizzes and commercial anatomy tutorial and quiz CD-ROM packages. In addition, activities associated with 2–4 radiological images viewed on light boxes, drawn from a repository of over 600 images held within the department, and a commercial radiological anatomy CD-ROM package accessible on one computer due to license restrictions, were available. Student access to the anatomy laboratory and its resources was available for independent study outside of scheduled teaching sessions and from the course website students could access self-directed online anatomy tutorials, quizzes, and clinical case studies developed within the institution in previous years. In 2007/2008, a patient-centered integrated spiral blended learning curriculum was introduced across Year 1 (‘Body in Balance’ systems-based approach) and Year 2 (‘Disturbance of Balance’ patient case-based approach). The redesigned curriculum was based on the following educational principles, set by the School of Medicine Curriculum Development Project Group in 2006: (1) clinical context for learning; (2) spiral learning of building upon and applying prior knowledge, skills and attitudes; (3) integration across systems and disciplines; (4) accommodating different student learning needs, styles and preferences; and (5) encouraging students to be independent and reflective learners. eLearning was a key to the delivery of the new curriculum, creating a blended learning environment that enabled students to review, reflect, apply, integrate, and contextualize their basic science knowledge in clinical context and to have an opportunity to experience interactive realistic clinical scenarios.

The new curriculum provided an opportunity to redesign the radiological anatomy teaching and learning in the early years of the curriculum. To broaden and deepen students’ learning of anatomy and radiology, within the student and staff curricular time constraints in the new curriculum, ways to include a wider range of normal and pathological images and more comprehensive activities utilizing the strengths of technology were explored. The work began with the Year 1 nervous and locomotor course, the first systems studied by Year 1 students after completing the 10-week foundations of medicine course. In the new curriculum, the previous 6-week locomotor course (lectures 5 hr; practical sessions 18 hr; tutorials 3 hr) was transformed into the 4 week nervous and locomotor course that encompassed gross anatomy of the upper and lower limbs (lectures 6 hr; practical sessions 8 hr; tutorials 2 hr) on which the Year 2 nervous and locomotor course builds on. Existing course online learning resources were limited in meeting the needs of the radiological anatomy teaching and learning with its coverage limited to anatomy alone. A search for external solutions at the time revealed no feasible, affordable TELT solution, and the underlying reasons were as follows. Firstly, the content was designed for radiology trainees and was not at an appropriate level for the intended Year 1 medical students (Phillips et al., 2013; Pinelle et al., 2012; Webb et al., 2013). Secondly, the TELT solutions that were relevant to medical students were primarily designed for use in conjunction with cadaveric dissection, which was not part of the Year 1 curriculum at the University of Southampton (Chew et al., 2006; Jacobson et al., 2009; Lufler et al., 2010; Marker et al., 2010; Tam et al., 2010). Thirdly, many offered passive activities such as viewing radiology images or studying digital images by controlling the visibility of labels on the images (Khalil et al., 2005, 2008; Marker et al., 2010; Radiol Educ, 2013; Turmezei et al., 2009). Furthermore, a review of the literature revealed little evidence of how these solutions work. With the increasing interest in radiology education and growing number of computer-based materials available for radiology education, there is huge demand for understanding how TELT works for teaching and learning radiology (Marker et al., 2010; Tam et al., 2010).

A new solution with which the faculty could support the educational principles of the new Southampton curriculum and enhance radiological anatomy education was required with the need to quantitatively assess the effectiveness and efficacy of the solution as a pedagogical tool for radiology teaching and learning (Khalil et al., 2008; Lufler et al., 2010). A TELT solution, called “Radiological Anatomy (RA) eLearning”, was designed to provide content appropriate for Year 1 students and active learning opportunities, and it was...
integrated to the curriculum not just as a student learning resource but as a useful teaching aid to be used in curriculum activities to optimize student use and benefits. A pilot study was conducted with its introduction in January 2009, and students’ responses to RA eLearning were positive. In 2010/2011 academic year, a formal and systematic evaluation was conducted using a mixed-method approach. The present article centers on the results of and findings from the mixed-method study conducted to perceive the impact of RA eLearning as derived from an evaluation of student use, perceptions and performance.

METHODS

Radiological Anatomy eLearning Development and its Integration in the Curriculum. The authoring of RA eLearning subject contents, curriculum integration, delivery strategy and staff development were led and conducted by the Nervous and Locomotor Course Coordinator (A.L.W), the design and development, including the learning design, were performed by the Faculty eLearning Manager (S.C), and the delivery was supported by the academic teaching staff and faculty eLearning team. RA eLearning was created by first devising student-centered learning outcomes that described what students should be able to do on completion of RA eLearning: identify and describe the normal radiological features of the bones and joints of the upper and lower limbs; differentiate the radiological features of the bones and joints of adults compared to children and teenagers; apply knowledge of the normal radiological features of the upper and lower limbs to identify and describe abnormalities of the bones and joints. One hundred and two hard copy X-rays, demonstrating normal and pathological anatomy of the upper and lower limbs, were digitized from the Centre for Learning Anatomical Sciences (CLAS), Faculty of Medicine, University of Southampton repository. In the first year of the new curriculum (2007/2008), a prototype was developed with the X-ray images displayed in PowerPoint and associated activities in an accompanying Word document. Students’ responses were very positive, and the success of the proof-of-concept trial with PowerPoint and Word and feedback from students led to the development of a TELT solution, RA eLearning, to allow students to interact with tasks and receive immediate feedback. Implemented in 2008/2009, it comprises interactive identification-based (Fig. 1) and guided learning activities (Fig. 2), including drag and drop, selecting areas, fill-in and multiple choice questions with immediate feedback, on-going scoring and final performance feedback (see SoM, 2013).

Radiological Anatomy eLearning was introduced to students at the beginning of the course in the first introductory lecture session with email reminders directing students to the website link during the course. RA eLearning was embedded and utilized within lecture and anatomy practical sessions where it was linked to the relevant anatomy being studied.

Figure 1.

An activity page interface and layout showing an interactive identification-based activity for normal radiological images. The interface design was based on a traditional ‘medical paper file’ system. Each screen presented the instructions, tasks, associated radiological image, feedback, score, and navigation buttons. The integrity of the image was maintained by labels that did not obscure the relevant radiological features while allowing the user to engage in the task. Movable notes and a scroll function for feedback were used to overcome the limited space without compromising the simplicity of the interface.
and provided an opportunity for discussion. For example, within an interactive lecture building the three-dimensional anatomy and clinical relevance of the cubital fossa, students were given an opportunity to apply their gross anatomical knowledge to the normal radiological anatomy of the elbow joint with an introduction to the radiological features associated with radial head fracture. RA eLearning was accessible on computers in the anatomy laboratory for use alongside activities involving the study of prosected cadavers, plastic models and bones; was made available on the course website (accessible 24 hours a day worldwide) for independent learning; and formed part of the course interactive Virtual Patient, an animated clinical scenario that illustrates a patient journey with embedded activities and tasks with immediate feedback, guided learning materials, and personalized performance feedback and recommended learning that are mapped to learning outcomes at the end (Fig. 3) (Choi et al., 2010). The Course Coordinator (A.L.W) organized and managed practical sessions, and invited and inducted radiology trainees from the local teaching hospital to attend one practical session each to assist in facilitation of RA eLearning (Chowdhury et al., 2008).

Radiological anatomy questions formed part of the nervous and locomotor course formative and summative assessments. The summative Integrated Anatomy Practical Paper (IAPP) assessment at the end of the course, comprising thirty, 1-minute stations (two questions per station), examined student ability to identify and describe the function of anatomical structures and to apply anatomical knowledge. It included questions relevant but different to RA eLearning (upper and lower limb bone and joint anatomy and X-rays), requiring students to apply and integrate their current anatomical and radiological knowledge and skills. The remaining IAPP questions included anatomy (upper and lower limb muscular and nervous system anatomy), histology and embryology not relevant to RA eLearning. The IAPP underwent a standard setting process using the Ebel's method by eight academics not involved in the research study (Bandaranayake, 2008; Friedman Ben-David, 2000). The Ebel's standard set pass marks for the questions relevant and not relevant to RA eLearning were of equivalent difficulty, 55% and 49%, respectively.

**Evaluation.** The effectiveness of the TELT solution in improving student learning experience in radiological anatomy and the appropriateness of its integration in the curriculum during the nervous and locomotor course was investigated in the 2010/2011 academic year. The study was approved by the University of Southampton, Faculty of Medicine Ethics Committee (project #SOMSEC 070.10). All first year medical students (n = 211) were invited to participate, and informed consent from participants was obtained at the beginning of the course. A mixed-method approach of qualitative and quantitative methods, which included: (1) Pre- and post-tests, (2) Summative course assessment by Integrated Anatomy Practical Paper (IAPP), (3) Questionnaire, (4) Focus groups, and (5) Tracking data, was used to collect data for triangulation (Johnson and Onwuegbuzie, 2004; Tashakkori and Teddlie, 2003).
Pre- and post-tests were conducted under assessment conditions at the first and final lecture sessions of the course. Each test was composed of ten single best answer questions (five options to select from, 30 sec allowed per question). Based around an X-ray each question assessed integrated anatomy and radiology knowledge and skills using identification and application type questions.

The summative course assessment (IAPP) results were analyzed to investigate if use of RA eLearning influenced student performance. Students’ performances for RA eLearning related questions and non-RA eLearning related ones were compared.

A questionnaire, conducted at the final lecture session of the course, assessed student use of RA eLearning and its impact on their learning experience. The first section consisted of closed and open-ended questions to obtain demographic data on the study population, determine student use of RA eLearning and ascertain their views and perceptions of the benefits and appropriateness of RA eLearning, including identification of what they most liked or did not like, found helpful or not helpful, and suggested improvements. The second section investigated students’ learning experience with RA eLearning, using a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree), on questions related to its usability, their engagement and interaction with it, and their interest in and enjoyment of learning the two subjects, the effectiveness of the solution in supporting the course learning outcomes and its impact upon their knowledge acquisition and application and contextualization of anatomy and radiology.

Focus groups, formed of randomly selected students, were held at the end of the course. Semistructured questions, which were purposefully open-ended and exploratory, were used to explore students’ views on and experience with RA eLearning and its impact on their learning of anatomy and radiology in relation to their learning with other curriculum activities. The focus groups were audio taped, transcribed, coded, classified and analyzed.

Tracking web usage data, which is one of the Faculty’s standard audits for online learning resources, was used to investigate how many students used RA eLearning, how many times and when. The tracking data from previous years were also reviewed to assess if there was a common trend in how students used the TELT solution and when.

Analysis. The collected data were analyzed in five areas: student use of RA eLearning, usability, student performance and student learning experience with RA eLearning. The descriptive data from the questionnaire was presented as percentages, ordinal data as median scores with the interquartile range and ratio data as the mean with standard deviation. Based on self-reported questionnaire data related to RA eLearning use, subjects were divided into two groups: students who had used (‘users’) or not used (‘nonusers’) RA eLearning during the course. After testing for Normal distribution using histograms with normal curves, quantile–quantile plots and the Kolmogorov–Smirnov (KS) test, the pre- and post-test results were compared between the two groups using analysis of covariance. Paired t test with 95% confidence interval was used to compare the scores between the IAPP questions relevant and not relevant to RA eLearning. A probability level of \( P = 0.05 \) was set as the minimum criterion of statistical significance for all tests. All analyses were performed using SPSS statistical package, version 17.0 for Windows (SPSS Inc., Chicago, IL). Thematic analysis method was used for qualitative
data, collected from questionnaire open-ended questions and comments and focus groups. Fisher’s exact test was performed to investigate quantitative and qualitative data as a whole.

**RESULTS**

**Participants**

Of the 211 students in Year 1 at the time of the study, 165 (78%) students (41% males; 59% females) aged 17–32 years (mean 19.5; SD ±2.1) provided written informed consent in the first week to participate in the study. Among the consented students, 116 (56%) responded to the questionnaire, 30 (14%) participated in the focus groups, 159 (76%) completed the pretest (mean score 37%; SD ±13) and 114 (55%) the post-test (mean score 47%; SD ±14), and among them 109 (52%) students completed both tests and the questionnaire. Of the 209 students who sat the summative IAPP assessment, 163 (78%) had consented to participate in the study (mean score 65%; SD ±14).

**Student Use of RA eLearning.** Since it had been made available in January 2009 to date (May 2012), RA eLearning has been used by 781 Faculty of Medicine students (3,525 times access by 631 students in Year 1; 133 by 54 in Year 2; 82 by 24 in Year 3; 18 by 9 in Year 4; 31 by 11 in final year; 143 by 52 graduate entry students) with an average five times per student. It was also used by 55 academic, research, and clinical staff. During the study period from December 2010 to September 2011, 167 of Year 1 students (79%) used RA eLearning, and Figure 4 presents the details from the beginning of the nervous and locomotor course to the end of the assessment re-sit period.

As illustrated in Figure 4, 135 students (64%) used RA eLearning during the nervous and locomotor course. The number includes 72 (34%) questionnaire participants who completed pre- and post-tests and reported that they had used RA eLearning (users). In the questionnaire 28 students (13%) who completed pre- and post-tests said that they had not used RA eLearning (nonusers), and 9 students (4%) did not answer this question; 81% of questionnaire respondents indicated that they intended to use RA eLearning for their revision (for summative assessments). Among the 28 nonusers, 20 students commented that they had planned to use RA eLearning during the revision week prior to the course assessments, purposefully keeping it for revision, citing “Will use it for revision week, as I believe this is how they can be utilized most efficiently.” One hundred 32 students, including 33 new users, used RA eLearning during the revision and summative assessment period, supporting students’ responses to the questionnaire. Additional reasons for not using RA eLearning included forgetting the website link (2), difficult to use the Faculty learning management system (1), inaccessibility of RA eLearning due to a broken laptop (1), and heavy learning loads (1). It was evident from the focus group that students liked to use RA eLearning at home for independent learning outside of scheduled teaching sessions.

Seventy seven percent of questionnaire respondents reported that they would recommend RA eLearning to fellow students, and 74% were interested in using RA eLearning in the later years of their degree. The tracking data revealed that the number of later year (Years 2–5) student users was gradually increasing between the 2009/2010 and 2011/2012 academic years. For example in the 2011/2012 academic year, the year following this evaluation study, 67 Year 2 to 5 students used RA eLearning, and 26 were Year 2 students. Within the 72 user group students 29 (40%) used it once, 25 (35%) twice, 14 (19%) three times and 2 (3%) more than three times. The mean time spent using RA eLearning was 92 (SD ±52) min.

**Usability of RA eLearning.** The majority of the questionnaire participants showed positive responses to usability aspects of RA eLearning. Sixty students (81%) agreed or strongly agreed that RA eLearning was easy to use. Five students (7%) who disagreed with the statement were ones who had reported problems accessing RA eLearning and who had not wanted to use it for learning.

In addition, out of 74 students who responded to these questionnaire items, 57 students (77%) agreed or strongly agreed that they enjoyed learning with RA eLearning, 50 students (68%) that they felt in control of their learning and 56 (75%) that RA eLearning actively engaged them in their learning. These were reinforced by the participants’ responses to the open question regarding the features of RA eLearning. They liked most or found most helpful.

**Student Performance.** The mean score increased significantly \[t(108) = 5.13, P < 0.001\] between the pretest (mean 37%; SD ±14) and the post-test (mean 47%; SD ±14). There was no significant difference in the post-test scores between the user (mean 48%; SD ±15) and nonuser (mean 45%; SD ±13) groups using the pretest score (user mean 38%; SD ±14 and nonuser mean 36%; SD ±13) as a covariate, which took into account any pretest differences between the groups \(P = 0.69\). There was a significant difference in summative IAPP assessment performance between RA eLearning relevant (mean 80%; SD ±16) and RA eLearning not relevant (mean 63%; SD ±15) scores \[t(162) = 14.7, P < 0.001\]. The influence of gender, number of times RA eLearning used and amount of time spent using RA eLearning prior to the revision week was explored but no trends were evident.

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**Figure 4.**

Usage of radiological anatomy (RA) eLearning by Year 1 nervous and locomotor course students \(n = 211\), of the 3-year Bachelor of Medicine degree, during the 2010/2011 academic year.
Student Learning Experience with RA eLearning: Meeting The Education Needs. Sixty-nine percent of questionnaire respondents cited that RA eLearning provided an opportunity to apply their knowledge of anatomy in a clinical context and was composed of a suitable amount of content (61%) and degree of difficulty (52%). Students reported that RA eLearning met the learning outcomes for normal radiological anatomy (79%) more than age-related differences (54%) and abnormalities (59%) (Table 1). Radiological Anatomy eLearning helped students to understand (85%) and revise (80%) anatomy and appreciate the clinical relevance of anatomy (62%) (Table 1). An increased interest in radiology was reported by half of the questionnaire respondents, and 69% related that inclusion of RA eLearning within the course Virtual Patient had helped them appreciate the use of radiology in a clinical context (Table 1).

Student Learning Experience with RA eLearning: Benefits Identified. Student responses to the open question “Identify one most significant benefit RA eLearning offered for your learning” was categorized and the key themes that emerged are presented in Figure 5.

Application of anatomy knowledge in a clinical context, i.e., anatomy in relation to radiology, was the most cited significant benefit (36; 49%), and it is associated to the content and its design. Next most commonly cited were revision and test knowledge (29; 39%), feedback and interactivity (13; 18%), and they are associated to the utilization of the strengths of technologies and interactions design.

Student Learning Experience with RA eLearning: Conflicting Results. In addition to the learning benefits offered by RA eLearning, students also identified various aspects that could be improved, and these included “more coverage for other imaging techniques, pathology/clinical and other topics” (14 responses from the “liked least” question and 34 from “suggestion for improvement”); “more detailed, individualized feedback providing links to associated resources when a question was answered incorrectly” (8 from the “liked least” question, and 5 from “suggestion for improvement”);

Table 1.

<table>
<thead>
<tr>
<th>Question</th>
<th>N</th>
<th>Mean</th>
<th>±SD</th>
<th>Median (IQ range)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meeting radiological anatomy learning outcomes relevant to the upper and lower limbs.</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RA eLearning was useful in helping me to identify and describe normal radiological features.</td>
<td>74</td>
<td>4.0</td>
<td>±0.9</td>
<td>4 (4–5)</td>
</tr>
<tr>
<td>RA eLearning was useful in helping me differentiate the radiological differences found at different ages.</td>
<td>74</td>
<td>3.5</td>
<td>±1.1</td>
<td>4 (3–4)</td>
</tr>
<tr>
<td>RA eLearning was useful in helping me identify and describe abnormalities of the bones and joints.</td>
<td>74</td>
<td>3.7</td>
<td>±0.9</td>
<td>4 (3–4)</td>
</tr>
<tr>
<td><strong>Application and contextualization of anatomical knowledge and skills.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA eLearning was useful in helping me understand the anatomy of the upper and lower limbs.</td>
<td>73</td>
<td>4.0</td>
<td>±0.9</td>
<td>4 (4–4.5)</td>
</tr>
<tr>
<td>RA eLearning was useful in helping me appreciate the clinical relevance of anatomy.</td>
<td>73</td>
<td>3.7</td>
<td>±0.9</td>
<td>4 (3–4)</td>
</tr>
<tr>
<td>RA eLearning helped me apply my knowledge of anatomy in a clinical context.</td>
<td>74</td>
<td>3.8</td>
<td>±1.0</td>
<td>4 (3–4)</td>
</tr>
<tr>
<td>RA eLearning helped me identify areas of anatomy where my knowledge and understanding are insufficient.</td>
<td>73</td>
<td>4.0</td>
<td>±1.0</td>
<td>4 (3–5)</td>
</tr>
<tr>
<td>RA eLearning helped me revise anatomy.</td>
<td>74</td>
<td>4.0</td>
<td>±1.0</td>
<td>4 (4–5)</td>
</tr>
<tr>
<td><strong>Introduction to and experience of radiological imaging.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA eLearning helped me become familiar with digital radiological imaging.</td>
<td>74</td>
<td>3.8</td>
<td>±0.9</td>
<td>4 (3–4)</td>
</tr>
<tr>
<td>RA eLearning has increased my interest in radiology.</td>
<td>74</td>
<td>3.4</td>
<td>±1.0</td>
<td>3.5 (3–4)</td>
</tr>
<tr>
<td>Having RA eLearning embedded in the Virtual Patient helped me see how radiology is used in a clinical setting.</td>
<td>74</td>
<td>3.9</td>
<td>±1.1</td>
<td>4 (3–5)</td>
</tr>
</tbody>
</table>

Student response on a 5-point Likert scale (1 = strongly disagree, 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree); mean, standard deviation (±SD) with the median score and interquartile (IQ) range are listed above.
“clearer images” (5 responses); “a stronger curriculum link around the quiz” (2 from the “liked least” and 4 from the “suggestion for improvement”) and technological issues. There were some conflicting responses about the amount “too much and not enough” and difficulty of the contents “too easy and too difficult” (8 responses).

DISCUSSION

Radiological Anatomy eLearning and its delivery in the curriculum were successful in implementing the educational principles of the new Southampton curriculum and enhanced the teaching and learning of both anatomy and radiology by providing active and contextualized learning opportunities at an appropriate level. RA eLearning in the curriculum supported the transition from hard copy images with limited student access viewed on view boxes to the digital delivery of images and activities. Students were able to access a greater number and variety of images in association with more in-depth and comprehensive activities, with minimal increases to scheduled curricular staff and student time. Furthermore, the experience with RA eLearning helped students see the clinical relevance of anatomy and increased student interest in radiology.

Meeting the Integrated Radiology Education Needs and Curriculum Educational Principles. Technology enhanced learning and teaching (TELT) solutions, such as RA eLearning, can help overcome many challenges that radiology and anatomy teaching and more widely the modern medical curriculum face. The challenges include effective facilitation of active and autonomous student-centered learning; implementation of practical experiences early in the curriculum; integration of basic and clinical sciences to help students appreciate the relevance of basic science to medical practice; curriculum efficiencies to account for reductions in formal anatomy instruction; and combining rather than replacing existing anatomical educational methods and resources with TELT solutions (Ahmed et al., 2011; Bowe et al., 2009; Dettmer et al., 2010; Gould et al., 2008; Nieder and Borges, 2012; Rizzolo et al., 2010; Rudland and Rennie, 2003). Compared to other previous studies in which students had passive access to radiological images or explored digital images by controlling the appearance of labels (Khalil et al., 2005, 2008; Marker et al., 2010; Radiol. Educ., 2013; Turmezei et al., 2009), RA eLearning in the curriculum offered active learning opportunities for students by the creation of quizzes and guided learning materials with feedback and scoring, which encouraged students to apply, evaluate and reflect upon their knowledge using self-testing. The active learner engagement in the learning process, in combination with user-control over the delivery of the information, supported and promoted the educational principles of independent student-centered learning in the curriculum. Incorporation of RA eLearning in a Year 1 course in association with the Virtual Patient and anatomy teaching provided an opportunity for contextualized learning, applied learning and integration of basic and clinical sciences. As Table 1 shows, student learning of anatomy becomes more meaningful and relevant when it is learnt in the context in which they will use it (Bohl et al., 2011; Dettmer et al., 2010; Rizzolo et al., 2006). Contextualization and integration enhance knowledge retention, understanding and satisfaction, yet can be difficult to achieve in the development and integration of TELT solutions (Howlett et al., 2011; Kourdioukova et al., 2011a; Rizzolo et al., 2006). In agreement with previous studies, the results suggested that the benefits of RA eLearning extended beyond the application and contextualization of anatomy. RA eLearning and its delivery in the curriculum increased student interest in radiology and their enjoyment of learning the subject, and this will have positive influence on their appreciation of radiology in the practice of medicine and consideration of radiology as a career (Branstetter et al., 2008; Dettmer et al., 2010; Kourdioukova et al., 2011a; O’Malley and Athreya, 2012; Turmezei et al., 2009). The positive student perceptions regarding all aspects of RA eLearning and its integration concur with previous studies that found a new electronic learning format, integrated with existing course activities forming a blended learning approach, to be associated with consistently high levels of student satisfaction, favorable attitudes towards learning and positive impact on knowledge acquisition (Howlett et al., 2011; Khalil et al., 2005; Kourdioukova et al., 2011b).

Student Use. Consistent with the positive feedback received, Southampton students made significant use of RA eLearning. This is in contrast to previous studies in which students and teachers had been slow to embrace new educational methods (May et al., 2013). The results suggest that the following factors are likely to have contributed to nearly all students using RA eLearning prior to the assessments: (1) good usability of RA eLearning; (2) the new curriculum being designed for and delivered in a blended teaching and learning mode; (3) staff training prior to the course commencement ensuring an effective and coordinated use of RA eLearning in teaching situations; and (4) radiological anatomy being included in the summative assessments. Positive feedback on and recommendation of RA eLearning from their fellow students may have also contributed to its high use.

First, the ease of using RA eLearning is likely to have positively influenced students’ use of and perception about RA eLearning (Table 1). The intuitive interface and effective learning design of RA eLearning required no instruction or training with minimal problems of its access none of which had been caused directly by RA eLearning, unlike many externally created systems that require instructions, guidance or basic navigation functionality (Khalil et al., 2008; Marker et al., 2010). Areas for improvement of RA eLearning reported by students were in agreement with previous studies...
(Marker et al., 2010; Turmezei et al., 2009) and included the incorporation of additional imaging modalities and body regions and more pathological abnormal images. Secondly, the new blended teaching and learning curriculum helped students become familiarized with using and taking advantage of TELT in their learning context. Furthermore, staff training offered prior to the course commencement promoted active engagement from teaching staff and active introduction of RA eLearning from teaching staff to students, helping students see the relevance and benefits of RA eLearning for their studies. Students cited that they preferred to use RA eLearning from home rather than during scheduled sessions or at student computers on campus, a finding shared by Marker et al. (2010). However, this was when a RA eLearning session was offered without other accompanying teaching activities. It highlights the importance of designing a face-to-face curriculum session that uses a TELT solution in conjunction with other teaching activities to enhance both teaching and learning.

Next, in agreement with Nieder and Borges (2012), highest use occurred during the relevant course and before summative assessments with lowest use after summative assessments along with further peaks of use prior to re-sit assessments. Southampton students were aware that radiological anatomy would be examined at the end of course summative assessments. It influenced student perception on the importance of the topic and helped them see the benefits of RA eLearning for preparing for the assessment. This is reflected in the higher use compared to previous studies where students used the resources less when they were supplementary or perceived to be extraneous compared to mandatory or testable activities (Bohl et al., 2011; DiLullo et al., 2009; Marker et al., 2012). Student use of RA eLearning was consistent with their comments that they had ‘saved’ RA eLearning or planned to repeat RA eLearning for revision suggesting that they had their own strategic approaches to learning and assessment preparation and these, with their perception of the role of RA eLearning, influenced their decision for the timing of when they used it. Nieder and Borges (2012) found that student use of online resources is dependent on fundamental differences in students’ preferred learning styles in addition to motivation factors, personality type and gender. The results from this study however did not show any significant difference between genders. The reason might be that RA eLearning was introduced as one of the core learning resources instead of a supplementary one. Reasons for not using RA eLearning were similar to those reported by McNulty et al. (2009) and could have been addressed with sufficient student motivation.

The opportunity for ongoing learning and revision offered by RA eLearning was evident by repeated student access although there were no trends evident to indicate whether this had an impact upon student performance (Fig. 4). The majority of students indicated that they would like to use RA eLearning in the later years of the BM program, which is supported by its increasing use by Year 2 to Final Year students. It suggests that RA eLearning meets individual students’ diverse learning and review needs in addition to supporting vertical integration of anatomy and radiology within the curriculum. Students appear to be motivated to use their independent study time productively when provided with relevant purposeful TELT and curriculum integration solutions. Thus TELT can enhance student learning and satisfaction and facilitate student-centered independent study (Rizzolo et al., 2010).

**Student Performance.** The majority of students reported that RA eLearning addressed the course learning outcomes for radiological anatomy. The higher scores for questions relevant to radiological anatomy in the course summative IAPP assessment demonstrate the positive impact of RA eLearning and its integration on student performance, in comparison to the scores for questions not relevant to radiological anatomy (muscular and nervous system gross anatomy, histology and embryology) that did not have a new distinctive solution created to support teaching and learning. In contrast, RA eLearning use did not significantly affect student performance during the course when investigated using pre- and post-tests as the measurement tool. However, this is most likely due to multiple exposures to RA eLearning in the radiology teaching experienced by the cohort through its integration strategy in the curriculum. RA eLearning was integrated to face-to-face lectures, laboratory sessions and course Virtual Patient, and used as a teaching aid as well as being available for independent learning. Both user and nonuser groups benefited from its use in the teaching sessions, and although not statistically significant the user group’s post-test scores were higher as a result of using it additionally for independent learning.

No single teaching modality can effectively support to meet all curriculum learning outcomes (Kerby et al., 2011; Patol and Moxham, 2008; Phillips et al., 2012). Most real educational contexts have multimethod teaching and learning approaches, and various individual and contextual factors influence teaching and learning. These make it impossible to isolate a single cause and its effect on learning in a real world environment (Bohl et al., 2011; Erkönè et al., 1990; Kourdioukova et al., 2011b; Phillips et al., 2012; Stanford et al. 1994). Employing a single method of data collection alone was limited in view of the conflicting student performance results of previous studies (Ketelsen et al., 2007; Phillips et al., 2012, 2013). What we can do is, using a mixed-method approach with methodological triangulation, trying to understand how the new intervention is working in the environment and making an inference on tentative cause and effect links between the intervention and results. The study reported in this paper has confounding factors from the context, and the results may not be replicated in different contexts. However, the study and its findings derived from multiple data sources have identified key factors to consider and a process to engage for successful TELT development, its integration and delivery.

**Limitations.** The present study has a number of limitations. The study was based on a TELT solution and integration strategy, developed for radiological anatomy teaching and learning in Year 1 curriculum at the University of Southampton. Therefore, the solution has a limited coverage, containing only X-rays of the upper and lower limbs, which covers only a part of the broader radiology curriculum. While we were able to provide a wide range of images and utilize our existing, albeit ageing, X-ray library, the use of high quality current digital images would improve RA eLearning in addition to the inclusion of additional body regions and imaging modalities, such as MRI, CT and ultrasound. Since the study, the University of Southampton has developed and introduced TELT packages for three other courses in Years 1 and 2. Next, the 56% questionnaire response rate was similar to previous studies and while likely to be a fair representation of the cohort as a whole, it is uncertain how students, who did not participate, would have answered the questionnaire and performed in the tests (McNulty et al., 2009; Marker et al., 2012). Thirdly, self-reporting was used to classify students into the user and nonuser groups. As a result, 42 students who did not participate in the questionnaire were not
included in the user group despite having used it. In addition, at least 125 students, including 33 new users, used RA eLearning prior to the end of course IAPP assessment but after the questionnaire. Discrepancies between tracking data and student responses have been previously documented (McNulty et al., 2009). In future studies, data collection can be improved with recording an individual student’s interactions with RA eLearning, including their answers to the questions, in a database. In future studies, the transferability of RA eLearning to different educational contexts, such as postgraduate entry and problem-based learning medical curricula, different health professions and medical schools in other universities and countries could be evaluated.

CONCLUSION

In conclusion, a TELT solution, which enhances teaching and supports active learning through effective design and integration into a curriculum creating a blended learning environment, can provide multiple opportunities for medical students to learn and revisit radiology. The results of and findings from the present study can be useful for the development and integration of TELTs for other institutions and educators who are interested in developing and implementing TELT radiological anatomy curriculum, and developing a new TELT solution or evaluating the existing ones for their curriculum. Key points for consideration include identification of clear curriculum needs; defining the roles of a TELT in the curriculum; effective learning design and integration strategies that support teaching and facilitate active learning opportunities; content design to engage the learner at a level appropriate to their current knowledge and skills; evaluation of the TELT solution in a real, complex educational environment despite it presenting many confounding factors; and appropriate infrastructure including staff development and training.

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LITERATURE CITED


