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Non-traditional subjects taught to engineers: a case study of teaching anatomy

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***Abstract**: Like many modern areas of engineering, bioengineering is a multidisciplinary subject. It is also one which necessitates that engineering students, who typically have minimal knowledge of medicine, must rapidly and successfully gain a thorough understanding of the intricacies of human anatomy as well as its dedicated language. Teaching on a Bioengineering module at a UK university employed a combination of Primal Pictures anatomical software, human joint models, bespoke teaching materials and peer-to-peer learning. This mixture allowed engineering students to quickly construct an understanding of anatomical principles which they used in individual, assessed projects on total joint replacement. Anonymised, written feedback collected from the students over consecutive academic years revealed overwhelmingly positive learning experiences. In addition, assessed projects showed good knowledge of the anatomical descriptions necessary to understand and work with the science of joint replacement.*

Introduction

One of the fascinating yet challenging aspects of modern engineering is its remarkably multidisciplinary nature. Straightforward examples include mechatronics, where a combination of mechanical engineering and electronics are successfully realised in millions of consumer products. Another multidisciplinary example is bioengineering, and data from the United States shows this discipline to be the fastest growing area of undergraduate engineering in that country (American Society for Engineering Education, 2008). In such nascent fields there is the need to quickly and effectively introduce engineering students to sciences and subjects that they may have not met previously.

Bioengineering improves medical interventions in many ways and one of its most important contributions has been through the design of replacement joints, such as those for the hip and the knee. How can engineering students quickly and effectively be taught human anatomy and gain a full understanding of the associated medical language such as coronal, metacarpophalangeal and inversion-eversion? One innovative method of learning could be provided through the use of models of human joints, and by employing dedicated software related to the anatomy and physiology of the human body. It is also recognised that, as IT systems become ever more common, and the needs of employers for computer-literate graduates becomes almost as fundamental as language proficiency, so the use of software to support learning is becoming commonplace (Abdul-Rehman and Davis, 2009).

Functional anatomy is a strongly three-dimensional subject where spatial visualisation is key (Van Sint Jan et al., 2003). Commentators have noted that medical students frequently encounter problems in understanding certain dynamic aspects of functional anatomy (Van Sint Jan et al., 2003) and this is likely to be the case with engineering students too. It has also been shown that the application of multimedia has helped students to increase their 3D anatomical understanding by giving them spatial direction about the underlying anatomy and its dynamic behaviour (Van Sint Jan et al., 2003). Additionally it has been noted that if students can interact with lecture content, then their assimilation of that material should be increased compared to situations where there is no opportunity to interrelate (Benbunan-Fich, 2002).

In the School of Mechanical and Systems Engineering at Newcastle University, the subject of Bioengineering is taught as a 15 credit module over two semesters to a combined group of fourth year MEng undergraduate students as well as postgraduate taught MSc students. In the 2008-09 academic year the author of this paper became module leader and began to teach one third of the module. For his third of the module, assessment became an individual, 3,000 word project based on an engineering critique of a commercially available design of total joint replacement. As such a critique needs to be founded on a full appreciation of the anatomy of the human joint that is being replaced, so the challenge was how to facilitate student learning of the complex subject of anatomy. In addition, for the majority of the bioengineering students, this would be the first time they had been formally introduced to anatomy and the associated medical terminology. The author began the module with a series of lectures on total hip replacement and biotribology. These gave appropriate background knowledge through a case study of the most common and successful type of joint replacement. After this, students were allocated an individual project where they were asked to critique a specific design of replacement joint and describe the anatomy of the relevant natural joint. Deliberately each of these projects was intended for one of the less commonly replaced human joints, specifically the shoulder, elbow, wrist, ankle and the various finger and toe joints.

By gaining a full understanding of the anatomy of human joints, the author of this paper intended that his Bioengineering students would appreciate the inherent challenges of joint replacement and the problems facing clinicians who have to implant such devices. To aid with this anatomical understanding the author of this paper was able to incorporate dedicated anatomical software as well as models of human joints into his teaching. The anatomical software chosen was Primal Pictures Systemic edition. Details of the software can be found on the company's website (http://www.primalpictures.com/). To date no formal independent evaluation appears to have been published and this paper may therefore offer the first such pedagogical assessment of the software. The models of human joints were purchased from 3B Scientific (Weston-super-Mare, UK). Models of the shoulder, spine, knee, hand, hip and foot were obtained and first introduced in the 2008-09 academic year.

The teaching methodology described above was repeated in the 2009-10 academic year, except that projects became paired. There were also two additions to the teaching. The static joint models were augmented with dynamic joint models, those that could be flexed in the same directions as human joints. Secondly, a two-hour visit to the dissecting room of Newcastle University's Medical School was arranged. Here, students were supervised by the Director of Anatomy and given access to human knee and hip joints.

The 3,000 word assignment allowed case-based, problem-based, and project-based learning, where students' learning was organised around attempts to solve authentic problems that occur in bioengineering. Such methods can help students develop the conditionalised knowledge and understanding that lets them think productively about problems in the discipline (Harris et al., 2002). One component of the 3,000 word assignment was that the anatomy of the particular joint had to be described. Here it was expected (and stated to the students) that Primal Pictures software be used. It is generally accepted that students' motivation for participation often arises not from a personal desire to learn but more from the requirement to attain marks (Case, 2007; Mann, 2001). Therefore this realisation of linking assessment to learning was taken into account.

Methods

Dedicated teaching materials were provided to the students in the form of bespoke training notes, written by the author, for the Primal Pictures software. Students worked through these notes with the software, in pairs, at their own pace, during dedicated sessions. The author of this paper led these sessions and was available to answer any questions which arose around anatomical principles or medical terminology. Similarly, the author produced bespoke training notes in relation to the human joint models. Here, students worked in self-selected groups to answer pre-set questions based around the models.

It has been noted that valuable features of web-based learning include its potential for empowering the learner, for enabling individualised instruction and collaborative peer-to-peer learning, and for transferring greater control to learners to decide when, how much, and to what extent study and instruction takes place (Curran et al., 2000). By presenting information and instructional materials in various formats, individual learning styles and preferences can be addressed (Curran et al., 2000). Similarly, Graff has noted that online material provides flexible learning, allowing learners to progress at their own pace, and they provide the facility for student-centred learning, making students responsible for their own learning (Graff, 2004).

By signifying that a fundamental understanding of anatomy is required to tackle subsequent assessed course material related to artificial joint replacement, and by pointing out how many people have their lives improved through joint replacement, it was considered that the ‘need to learn’ and the ‘want to learn’ aspects of Race’s model of learning would be facilitated (Race, 1994). Supervision was deliberately small group or one-to-one and non-hierarchical so that students felt they were gaining personal attention in a constructive learning environment, as suggested by Tinto’s model of integration (Tinto, 1975). Additionally the value of providing time for student-instructor and student-student interactions in the classroom has been shown (Roselli and Brophy, 2003). Students were paired up to tackle questions related to the software, and formed self-selected groups to answer questions related to the human joint models, thus encouraging immediate learning by doing and augmenting this through peer-to-peer learning. Both of these tactics supported Kolb’s ideas of experiential learning, thus facilitating deeper learning (Kolb, 1984). Moreover, it has been recognised that opportunities to work collaboratively can enhance students’ abilities to learn and can help students receive feedback about their thinking. In addition, using appropriate software is an interactive mode of learning (Abdul-Rehman and Davis, 2009). It has also been recognised that students learn more effectively when they actively participate in the learning process (Goodhew et al., 2006; Sivian et al., 2000).

In both the 2008-09 and the 2009-10 academic years, at the end of his third of the module, anonymised questionnaires were passed to the students by the author of this paper. The questionnaires contained a number of sections and were intended to gather feedback on this part of the Bioengineering module. The first section of the questionnaire consisted of ten questions which requested answers on a five-point scale. The second section asked the student to offer two good features of the course and two suggestions for improvement, before offering the opportunity for further comments to be made. The third section focussed on the ‘innovative’ features of the course, including the Primal Pictures software and the human joint models. Here the dedicated questions were ‘to what extent did Primal Pictures software help you to understand human anatomy?’; ‘if you accessed Primal Pictures software outside of taught sessions, to what extent was this useful?’; and ‘to what extent did human joint models help you to understand human joint anatomy’. For the 2009-10 academic year another question was added requesting feedback on the visit to the dissecting room of the Medical School of Newcastle University.

Results

Students interacted well with the software and asked very few questions related to navigating around the software, while the pairing mechanism encouraged pertinent discussion and sharing of opinion. It was also interesting to note the majority of students mimicking the actions of human joints shown on computer screens, for example by lifting their shoulders to imitate elevation or ‘wagging’ fingers to copy their flexion-extension motion.

Student feedback on use of the Primal Pictures software was overwhelmingly positive. Students said that using the software was ‘fun’ and ‘easy’ and one commented specifically about the learning experience, ‘the Primal Pictures software made me appreciate what a sophisticated and still not fully understood bearing the natural elbow joint is’. One student described the software as ‘an excellent graphical aid and introduction to the anatomical language’. Another said the Primal Pictures software was ‘very useful for the project, in naming bones and muscles and all related terms to do with the joint’. A fourth student offered this review of the software. ‘It was very good for learning about the muscles, ligaments and bones considering you had to click on each part’. A fifth student wrote ‘the Primal Pictures software was a huge help in understanding anatomy of joints’.

Another student offered the following verdict:

> ‘I found the software easy to use with its simple search and contents options’. ‘It was easy to navigate through the program’. ‘What I found most useful about the software were the interactive 3D models of the area of interest which could be rotated and altered. When looking at a specific joint it allowed me to appreciate the complexity of it in 3D but also made it very accessible to explore as each component within the joint could be highlighted by clicking on it, then the name and a brief description was given at the side of the model. The 3D models could also be built up layer by layer from the bone showing the different tendons, ligaments, muscles etc which allowed you to simplify your view of an otherwise complex “organ” within the body’.

Perhaps the most interesting comment about the Primal Pictures software was the following:

> 'With the program being so simple to use it urged me to look at other sections of the body out of interest purely as a learning experience. The program overall does not give a great deal of in-depth information about specifics within the body but its greatest ability is to show otherwise complex organs, joints and systems within the body in an interactive 3D way which is very user friendly'.

As with any software, suggestions for enhancement were offered. These included: 'could be improved to include the ability to drag joints to make them move'; and 'would be good if you could zoom out onto a hand/foot/knee from the whole skeleton rather than having to hunt through tabs'.

Two formal questions were asked of the students regarding the software, and an answer requested to each on a five-point scale. These questions were: 'to what extent did Primal Pictures software help you to understand human anatomy?'; and 'if you accessed Primal Pictures software outside of taught sessions, was this useful?'. In the 2008-09 academic year, twenty completed questionnaires were received from students, although one student did not respond to the second question, out of a class size of thirty. In the 2009-10 academic year there were fourteen questionnaires completed out of a class size of twenty-one. Results are shown in figures 1 and 2.

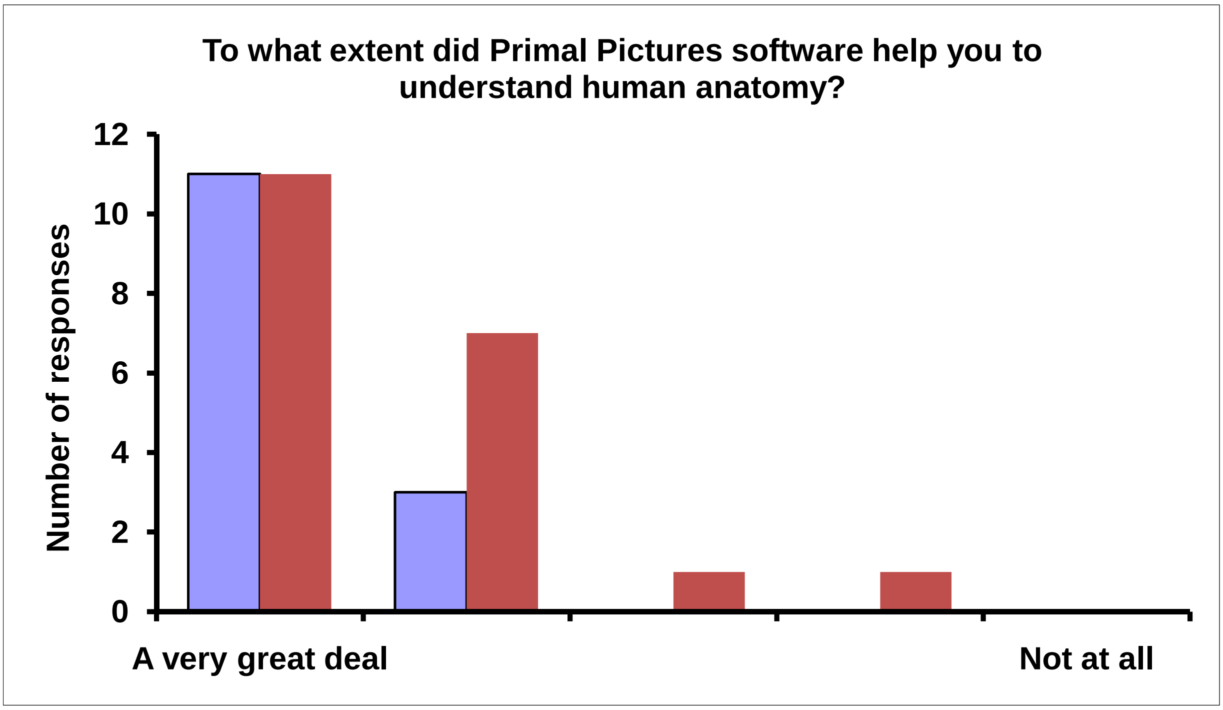

Figure 1. Students' answers to first specific question on use of Primal Pictures software (2009-10 academic year in blue, 2008-09 in red).

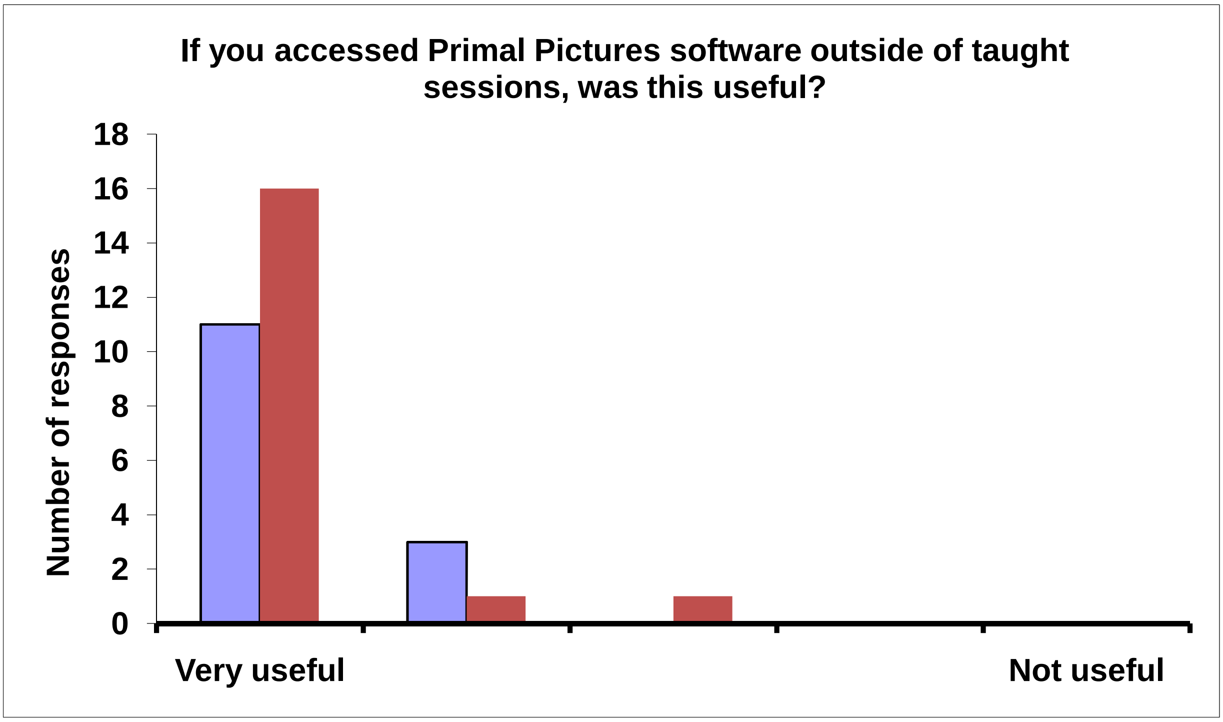

Figure 2. Students' answers to second specific question on use of Primal Pictures software (2009-10 academic year in blue, 2008-09 in red)

As can be seen from figure 1 the majority of students (90% in 2008-09 and 100% in 2009-10) thought that the software helped them to understand human anatomy a 'great deal' or a 'very great deal'. In addition, as indicated in figure 2, the majority of students (94% in 2008-09 and 100% in 2009-10) thought that it was 'very useful' or 'mostly useful' to be able to access the Primal Pictures software outside of the taught sessions.

The feedback on the human joint models was equally as positive. Responses to the question 'to what extent did human joint models help you to understand human joint anatomy' are shown in figure 3. As can be seen, the majority (80% or 16/20 in 2008-09, and 86% or 12/14 in 2009-10) answered in the two highest categories available.

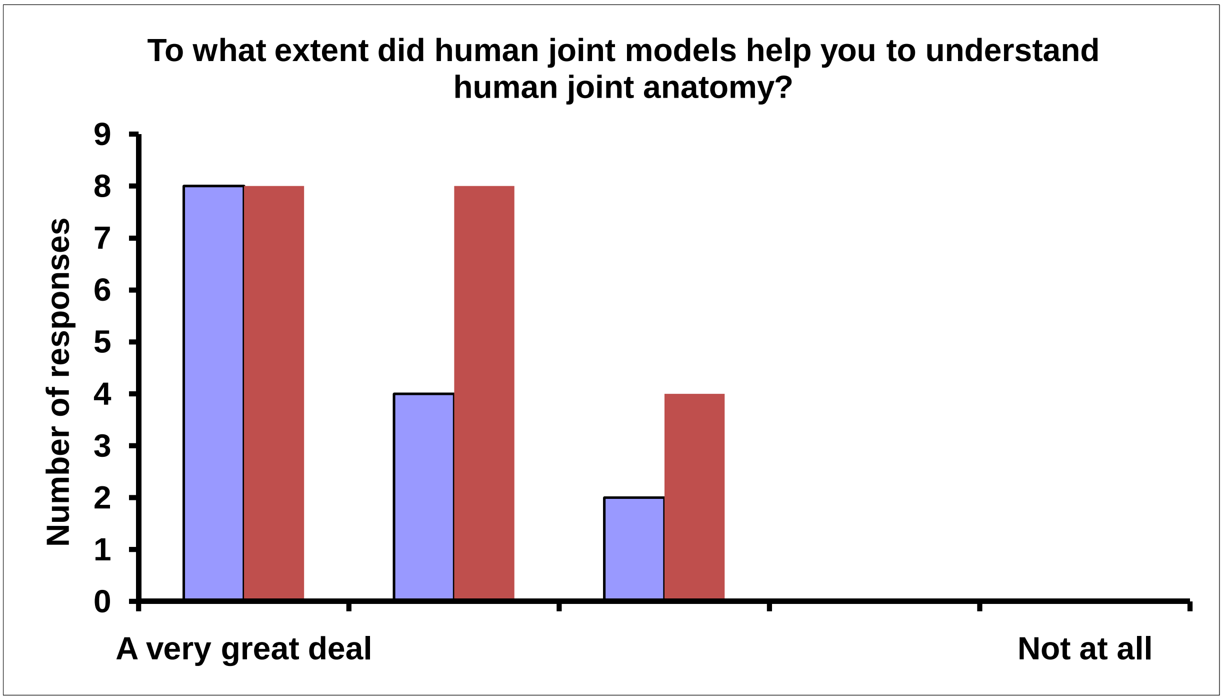

Figure 3. Students' answers to question on use of human joint models (2009-10 academic year in blue, 2008-09 in red)

From feedback at the end of the 2008-09 academic year, one student voiced the opinion that dynamic models, those which could be articulated, would have been preferred. This had been the original intention, but issues of cost (dynamic models are approximately three times the cost of static models) meant that less expensive static versions had to be selected. However, taking a lead from this student feedback, funding was obtained to allow the purchase of a small number of dynamic models (Adam Rouilly, Sittingbourne, Kent, UK). These were employed alongside the static models in the 2009-10 academic year.

As has been stated, in the 2008-09 academic year each student was assigned an individual project which concerned a critique of a currently available artificial joint. As part of this evaluation, students were asked to describe the anatomy of the relevant natural joint, describing the main bones, muscles and ligaments. The average mark awarded on this section of the projects was 62% and almost all the students had used Primal Pictures software to describe the appropriate natural joint thereby indicating the important role that the software had in their understanding of anatomy. This situation was repeated in the 2009-10 academic year, again almost all of the students employing data from the software to describe the joint they were critiquing.

Throughout his third of the module, in both academic years, the author of this paper employed small group and interactive teaching wherever possible. General feedback from students should therefore be seen in this light but students' comments as to positive aspects of the module included the following: 'entirely new and interesting topic, self directed learning (project)'; 'the project is good and I learned a lot'; 'very interactive learning, encouraged thinking/problem solving'; 'the software was useful, the teaching was very clear to us'; and 'course work assessment, no biology knowledge assumed'.

For completeness, it was also interesting to note student comments on their visit to the dissecting room of the Medical School of Newcastle University in the 2009-10 academic year. These remarks included: 'awesome experience'; 'fantastic class. Helped to reinforce what we had learnt in classes. Good to see firsthand how the materials differ and are similar to those of the prostheses'; 'extremely useful in understanding the joints'; 'greater appreciation for the complexity of the human body'; 'great chance to see real examples of joints and their relative movements'; 'anatomy class was superb'; and 'if time permits we should have more of these in future'.

Discussion

The software is expensive, at approximately £4,400 for one year's access for ten seats. However, it can be accessed from any computer connected to the World Wide Web, so that students are not restricted to where or when they can learn. Formal feedback showed that students appreciated this flexibility. According to the Primal Pictures website, the software is used in over 450 universities in more than 20 countries and in 2010 over 500,000 students will use it to learn anatomy. While the testimonials on the website are upbeat, no formal independent evaluation of the software appears to have been published; therefore this paper may offer some of the first such observations.

As with the software, there appears to be little in the pedagogical literature assessing the usage of human joint models. These were far less expensive and remain available for future years, and student feedback on them was almost as positive to that for the software. Student comments regarding the human joint models included: 'the clearest way to see and understand joint anatomy and movement'; 'good to get hands on, helped to gain an understanding about the scale of the joint'; and 'very interesting to see models you can touch'. For the 2009-10 academic year, dynamic models were used alongside static models. The difference between the two types was noted by student comments including 'the dynamic models were a great addition' and 'the models that move are much more effective than the static ones'.

Given the cost of the Primal Pictures software, it is worth considering anatomical software which is available for free on-line. One excellent source is the website Think Anatomy (http://thinkanatomy.com/). As with many websites, the content is regularly updated therefore this review acts as a snapshot at the time of writing (late January 2010). Think Anatomy acts as a single source of links to 'free' websites which are related to the teaching of anatomy. The first source investigated was the Visible Body (http://www.visiblebody.com/). However, it soon became clear that while an instructor could obtain free access, students had to pay an access cost of $36 per year. While this cost per student may be reasonable, it could also be seen that making the software available to a class of say 30 students would take the total cost to over $1000 per year. A comment on the Think Anatomy website implied that the Visible Body software had, until recently, been free but now a payment was required for access.

The next website investigated was Anatomy Arcade (http://www.anatomyarcade.com/). The website creator describes it as a collection of 'games' related to anatomy. This appears to be an accurate portrayal, and many of the games are fun to play. Conversely, there were distractions due to a great number of advertisements on the website, though these are said to be a necessary evil to allow the content to remain free. It is possible to purchase an advertisement-free version. The content of Anatomy Arcade is entertaining but, in the opinion of this author, the website would be best used to augment a second method of anatomy instruction, whether that comprises lectures, a text book or a second electronic source.

Get Body Smart (http://www.getbodysmart.com/) was the next website investigated. It describes itself as a website for teaching and learning the basic principles of human anatomy and physiology. In the opinion of this author, many parts of this website offered excellent material. For example, the muscles section was considered to be as good as or better than Primal Pictures, which can offer too great a level of detail than that required for students taking the Bioengineering module. However, this comment may not apply to other students, such as those of medicine, who may need a greater depth of knowledge of muscle physiology. One good feature of the free Get Body Smart software was the ability to add or remove one muscle at a time from a virtual limb. This made learning very clear-cut, although the software lacked the sophistication of Primal Picture's ability to rotate images on screen.

A fourth website investigated was that supplied by Merck (http://www.mercksource.com/ppdocs/us/cns/content/adam/visualbody/bgready.html). It should be noted that the url given on the Think Anatomy website is incorrect, indicating how quickly such links can become redundant. In the opinion of this author, it seemed that the resource had been developed by taking the content of a book and placing it on line. As such the strengths were that good, conventional descriptions of anatomy were offered. Another advantage was that, like with the Primal Pictures software, text and images could be copied from the Merck website and pasted to students' own reports. Unfortunately there were relatively few images on the Merck website and there was no interactivity offered by the software – whether in the form of games, quizzes or the ability to manipulate images on screen.

From this review of the various anatomical softwares, this author felt that the Primal Pictures software offered a single source of anatomical data, in a format which students could easily interact with. The Primal Pictures software is also remarkably comprehensive. However, these positive points come at a high financial cost. By combining free sources of anatomy teaching it is likely that similar learning of anatomy by engineering undergraduates taking a bioengineering module can be obtained. This low cost may be all the more important in many current contexts, particularly where the learning of anatomy will always be an adjunct to that of bioengineering.

Although no similar educational papers discussing the use of anatomical software could be found, one recent paper has described the use of subject specific software in an engineering context (Abdul-Rehman and Davis, 2009). Implicit in much of the Abdul-Rehman and Davis paper is the amount of work required in introducing new computer-based material to an engineering module. Explicitly these authors noted that an aim was for no increase in staff time when introducing the software. However, they mention devising workbooks, homework exercise and solutions. It is only towards the end of the paper that it is stated that all such work was done ‘through teaching assistant support which was funded by a teaching fellowship grant’ (Abdul-Rehman and Davis, 2009). This author feels that such honesty is commendable. While almost all engineering academics would likely agree with the idea that the student learning experience should be positive and enhanced by all the potential benefits of computer-assisted learning, its introduction requires significant resources not only in financial terms but also time from academics. Two further points from this author’s experience should be made. Firstly, software is updated regularly and so student instructional notes on the software have to be frequently updated too. Secondly, such instructional notes have to be 100% correct and incremental, in the opinion of this author. Start with a foolproof introduction and exercises, and allow students time to gain confidence with the software. Indeed the need for step-by-step guidance has been noted elsewhere with subject-specific software (Abdul-Rehman and Davis, 2009). Once confidence has been obtained, then students will have the opportunity of exploring the software as they wish and thus the possibility of an independent and deep learning experience.

Conclusions

The anatomical software, augmented by the use of models of human joints, allowed students to rapidly become familiar with a new area of learning from outside engineering. Combining the positive learning benefits of non-hierarchal, small group and peer-to-peer learning with innovative and novel teaching aids quickly and effectively enhanced the student learning experience of atypical material by a cohort of engineering students.

References

American Society for Engineering Education (2008) Engineering by the numbers. Available from http://www.asee.org/publications/profiles/upload/2007ProfileEng.pdf [accessed 31 January 2010].

Abdul-Rehman, S. and Davis, C. (2009) 'Independent learning using the Cambridge Engineering Selector (CES) EduPack software with large class sizes', *Engineering Education,* 4, (1), pp. 2-7.

Benbunan-Fich, R. (2002) 'Improving education and training with IT', *Communications of the ACM,* 45, (6), pp. 94-99.

Case, J. (2007) 'Alienation and engagement: exploring students’ experiences of studying engineering', *Teaching in HE,* 12, (1), pp. 119-133.

Curran, V. R., Hoekman, T., Gulliver, W., Landells, I. and Hatcher, L. (2000) 'Web-based continuing medical education (I): Field test of a hybrid computer-mediated instructional delivery system', *Journal of Continuing Education in the Health Professions,* 20, (2), pp. 97-105.

Goodhew, P., Murphy, M. and Mannis, A. (2006) Student attitudes to active learning *Engineering Education 2006.* Liverpool, UK, 24-26 July.

Graff, M. (2004) Cognitive style and attitudes towards using online learning and assessment methods *ECEL: the 3rd European conference on E-learning* Paris, France, 25-26 November 2004.

Harris, T. R., Bransford, J. D. and Brophy, S. P. (2002) 'Roles for learning sciences and learning technologies in biomedical engineering education: a review of recent advances', *Annual Review of Biomedical Education,* 4, (1), pp. 29-48.

Kolb, D. A. (1984) *Experiential Learning: Experience as the source of learning and development.* Eaglewood Cliffs, NJ, USA: Prentice-Hall.

Mann, S. J. (2001) 'Alternative perspectives on the student experience: alienation and engagement', *Studies in Higher Education,* 26, (1), pp. 7-19.

Race, P. (1994) *The Open Learning Handbook.* London: Kogan Page.

Roselli, R. J. and Brophy, S. P. (2003) 'Redesigning a biomechanics course using challenge-based instruction', *IEEE Engineering in Medicine and Biology Magazine,* 22, (4), pp. 66-70.

Sivian, A., Leung, R. W., Woon, C. and Kember, D. (2000) 'An implementation of active learning and its effect on the quality of student learning', *Innovations in Education and Training International,* 37, (4), pp. 381-389.

Tinto, V. (1975) 'Dropout from Higher Education: A Theoretical Synthesis of Recent Research', *Review of Educational Research,* 45, pp. 89-125.

Van Sint Jan, S., Crudele, M., Gashegu, J., Feipel, V., Poulet, P., Salvia, P., Hilal, I., Sholukha, V., Louryan, S. and Rooze, M. (2003) 'Development of multimedia learning modules for teaching human anatomy: Application to osteology and functional anatomy', *The Anatomical Record Part B: The New Anatomist,* 272B, (1), pp. 98-106.

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