Adv Physiol Educ 31: 261–265, 2007;
doi:10.1152/advan.00125.2006.

The positive impact of team-based virtual microscopy on student learning in physiology and histology

Harry R. Goldberg[1,2] and Renee Dintzis[1]

[1]*The Johns Hopkins School of Medicine and* [2]*Department of Biomedical Engineering, The Johns Hopkins University, Baltimore, Maryland*

Submitted 29 December 2006; accepted in final form 18 June 2007

Goldberg HR, Dintzis R. The positive impact of team-based virtual microscopy on student learning in physiology and histology. *Adv Physiol Educ* 31: 261–265, 2007; doi:10.1152/advan.00125.2006.—Team-based virtual microscopy and on-line learning were used to transform the first-year Physiology/Histology course at The Johns Hopkins School of Medicine into a student-centered learning environment. Prior to each laboratory session, students were required to view prelaboratory virtual lectures and examine digital slides that had been enhanced with annotations and 2-min microlectures. The laboratory classroom was then used for team-based learning exercises including student presentations and small-group discussions designed to integrate histology and physiology. The results of quantitative assessments indicated an 8- to 14-point increase over the identical final exams given over the past 5 yr. Means (±SD) of percent correct answers on the final exam were found to be 75.2% (11.1%), 72.5% (12.6%), 70.5% (12.6%), 73.6% (11.3%), 73.1% (12.2%), and 84.1% (9.1%) for years 2001–2006, respectively. The mean test scores for all other years were statistically lower compared with 2006, as determined by the Bonferroni post hoc multiple-comparison test ($P < 0.001$ for all years).

educational technology; active learning

THE USE OF TECHNOLOGY in medical education has focused on patient simulation, complex data visualization, and student assessment (4, 7, 10, 13, 15). In this study, the use of technology was extended into the first-year Organ Systems Histology course at Johns Hopkins to redefine the faculty member's role from provider of core content to facilitator of discussion. The primary motivators for changing the course's educational format included:

1) providing students with a core content resource that transcends the classroom.
2) encouraging students to actively explore and manipulate content (3).
3) exposing students to educational technology and increasing student comfort level with the use of technology as an analytic tool.
4) improving the quality of faculty-student interactions and supporting a paradigm shift from teaching to learning (9).
5) enabling students to review course content at any time.
6) standardizing content delivery and "immortalizing" a nonreplaceable glass slide collection.

The educational format used in the Organ Systems Histology course generated widespread support from faculty members and students. The grade point average on the four midcourse histology exams increased by 5–14 percentage points and on the final exam by 8–13 percentage points compared with scores on the identical exams given each year for the prior 5 yr. The SD on all of the 2006 exams was lower than it had been on any of the previous 5 yr's exams. Exams were not returned to students during any of the 5 yr of this study; therefore, positive results cannot be attributed to prior knowledge of content.

METHODS

The first-year Histology course is an 8-wk-long program serving the academic needs of 120 medical students. Organ Systems is divided into two sections: physiology and histology. These tracks are linked on an organ-by-organ basis. Historically, the only connection between histology and physiology has been that they were offered at the same time of year. In prior iterations of the Histology course, students were divided into four equal-sized laboratory groups. The laboratory would start with a 30- to 45-min introductory lecture. Students were then instructed to view their slide collection with the aid of a laboratory manual; a teaching assistant (TA) or the faculty member would answer questions and provide oversight during this exercise. End of course student evaluations indicated that this method of instruction had several weaknesses: *1*) students had difficulty understanding the importance of histology; *2*) student-student and student-faculty interactions and discussions were limited; and *3*) student enthusiasm for the course was low.

The 2006 version of the Organ Systems Histology course was redesigned to address these challenges. Prelaboratory instruction, an introduction to histopathology, and student presentations became central components of the new course. The number of the following laboratories was unchanged from years past: Renal, Respiratory, Skin, Muscle/Cardiovascular/Vessels, Gastrointestinal (GI)_1, GI_2, Liver, Endocrine, Female Reproductive, Male Reproductive, and Placenta (other organ systems were covered in different courses).

Prelaboratory instruction was divided into three sections: a 30- to 40-min web-based overview lecture, a series of slide-specific 2-min microlectures (also web based), and a set of virtual slides that were each enhanced with 4–15 annotations. There were 6–10 slides/laboratory, and these slides were delivered using the software program Neuroinformatica from MBF Bioscience (8). MBF Bioscience also digitized the slide collection used in this course. Students were expected to view prelaboratory lectures and slides at home or using the school's computing resources before each laboratory section of the course.

There were three methods used to record lectures:

1) Studio recording of the lecture followed by professional illustration of the content. This was the most expensive solution and had

Address for reprint requests and other correspondence: H. R. Goldberg, The Johns Hopkins School of Medicine, 115 PCTB, 725 N. Wolfe St., Baltimore, MD 21205 (e-mail: goldberg@jhmi.edu).

The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

the highest level of visual content; it was the only solution that included a video of the lecturer.

2) Annotating a PowerPoint presentation using a screen capture program (Camtasia) (12), a graphics tablet (Wacom Cintiq 15x) (17), and the audio recording of the laboratory lecture given the previous academic year. This was the least expensive of the three solutions.

3) The software application Breeze (Adobe/Macromedia) (1) was used to create a PowerPoint slide presentation that was enhanced with voice and annotated overlays. This approach was intermediate to the other two approaches in terms of both time and cost.

The professionally illustrated lectures and the annotated PowerPoint lectures were delivered using a QuickTime Streaming Server or, alternatively, a Real Server. The Breeze content was delivered using a Flash server.

Each in-class laboratory section had three components: *1*) a series of three 7- to 10-min student team presentations that focused on the link between histology, physiology, and pathology; *2*) a question and answer period; and *3*) a team-based online quiz. Student teams were formed by dividing the 120 medical students into 4 groups; the 4 groups were further divided into 10 three-person teams. A faculty member and two TAs were assigned to each group. To ensure ample time for preparation, topics for student presentations were assigned at the beginning of the course. Representative samples of student presentations included the following:

1) Skin section. In psoriasis, increased epidermal cell turnover results in marked epidermal thickening, with elongated, narrow rete pegs or ridges. Solve "mystery" *slides A* and *B* as they appear in the virtual microscope.
   A. (Histology.) Which slide illustrates pemphigus, and which slide illustrates psoriasis?
   B. (Histology.) What histological characteristics helped you make the diagnosis?
   C. (Physiology.) Give a brief description of patient symptoms in each disease.

2) Female reproduction section. (Physiology.) Discuss the relationship between stages of ovarian follicle maturation, phases of uterine endometrium, and cervical gland secretion.

3) Liver section. (Histology.) Compare low-power microscopic views of the liver and pancreas. What histological features of the liver differentiate it from the pancreas?

Prior to a team presentation, student team members met with their laboratory director and TAs. Time was used by students to rehearse presentations and by faculty members to address potential misconceptions. The role of the TAs was similar to that of the faculty member: to provide student guidance during the rehearsal presentations, potentially ask questions during the formal presentations, answer questions during the slide review component of the laboratory, and proctor the exams. This increase in contact time over previous years between faculty members and students was one of the highlights of the course.

Quantitative assessment of students was based on laboratory quizzes, four midterm exams, and a final exam. Laboratory quizzes consisted of 10 questions based on the prelaboratory lecture, slide annotations, microlectures, and student presentations (questions based on student presentations were formulated during the rehearsal period). Quizzes were delivered through Blackboard, the school's course management system. The four mid-term examinations required each individual student to identify histological sections that were presented via a LCD projector in the lecture hall. Questions on these exams were the same as for the past 5 yr; however, due to changes in the course schedule, the grouping of questions was not necessarily the same from year to year. The final exam was the identical exam used in prior years of this study with the exception that students used virtual microscopy rather than light microscopy to view the images. The format of the final exam was slide identification: students had 2 min to identify each of the 30 images, and they were not permitted to return to previous slides. The final exam and four midterm exams were not returned to students from year to year, so results of this study do not reflect prior knowledge of content. An overview of the course's format is shown in Fig. 1.

Statistical differences between mean scores by year were determined using one-way ANOVA followed by the Bonferroni post hoc multiple-comparison test. ANOVA tested the null hypothesis that all yearly means were equal, whereas the Bonferroni test allowed for multiple comparisons between yearly means while adjusting the overall α at 0.05. All statistical analyses were performed using STATA version 9.0 (11).

Steps to implementing virtual microscopy. Virtual microscopy can be implemented at the following three levels of sophistication (5).

LEVEL 1: DIGITIZED IMAGES FROM A LIGHT MICROSCOPE. This approach is simple to deploy and inexpensive to implement but is limited in terms of functionality (e.g., students are unable to alter magnification without loss in picture quality). Text or graphical overlays can be added to the images using a variety of image editing tools including Photoshop. The equipment necessary to reach this level of delivery is straightforward: a digital camera attached to a microscope. Files can be saved and added to the course website for viewing.

LEVEL 2: REMOTE CONTROL OF A LIGHT MICROSCOPE. When fitted with an electronic stage and focusing controls, a user is able to control the microscope from an offsite location. The benefits of such an approach include being able to view the actual slide and having full control of the microscope (focus, aperture, condenser, objectives, etc.). This approach, however, is not acceptable for most teaching activities: the slides cannot be changed by the user, and the bandwidth for sending each field of view is considerable and can be hampered by transmission delays. Furthermore, only one user can control the microscope.

LEVEL 3: SLIDE SCANNING AND VIRTUAL MICROSCOPY SOFTWARE. The third level of organization is the most versatile and yet the most expensive solution for using virtual microscopy in the classroom. The slides are digitized using a slide scanner, and the files, often in the gigabyte range, are stored on a high-capacity server. To avoid the high purchase cost of a scanner ($80–100,000), slides can be scanned by a variety of firms: MBF Bioscience (http://www.mbfbioscience.com) was used to scan the collection used in this study. The per slide cost is dependant on the area of the slide to be scanned, but $150 per slide is a reasonable estimate. The large size of the digitized images and the need for near-instant delivery of content across the internet requires that the scanned image be converted into a collection of "tiles;" this is a function of the scanning software. The virtual microscopy software produces dramatic performance gains by stitching together only those tiles in the field of view. Software for virtual microscopy can be acquired from a variety of firms, with Aperio (www.aperio.com) being a top contender.

RESULTS

The effectiveness of course design on knowledge gains and satisfaction levels was assessed two ways: *1*) statistical assessment of differences in mean test scores by year and *2*) a brief descriptive summary of survey responses.

Quantitative Assessment

Average test scores ($\pm$SD) on the midcourse exams (2002 GI/Liver, 2005 Renal/Respiratory, and 2005 Skin/Cardiovascular/Vessels) are shown in Fig. 2 (2001: $n = 126$, 2002: $n = 119$, 2003: $n = 120$, 2004: $n = 120$, 2005: $n = 120$, and 2006: $n = 121$). Exams that did not use the same grouping

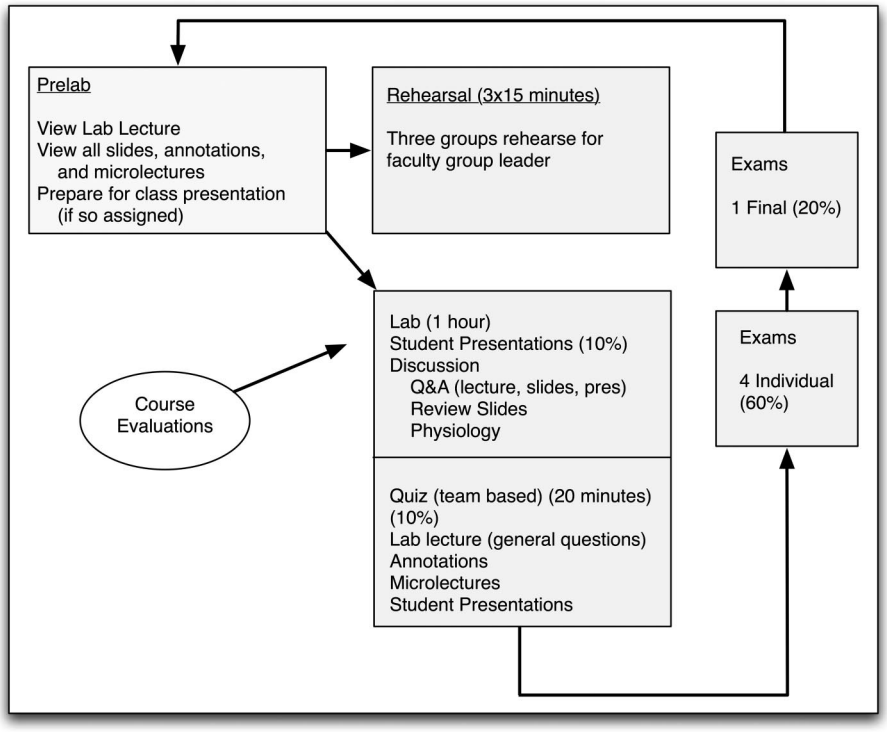

Fig. 1. Overall format used in the Organ Systems Histology course. The percent contribution of each section to the student's final grade is shown.

of content used on the 2006 exams are not displayed. The average score for each 2006 midcourse exam was 5–14 points higher than for any other exam, and the SDs are lower in 2006 than for any previous year. Differences in test scores for all previous years versus 2006 were statistically assessed by the Bonferroni test for multiple comparisons following one-way ANOVA. For the GI/Liver midterm, this analysis revealed statistically lower mean results for years 2001, 2002, and 2003 compared with year 2006 ($P < 0.001$ for all years). No statistical differences were found between the mean score for 2004 versus 2006 for the GI/Liver midterm exam. Mean scores on the Renal midterm for both 2004 and 2005 were statistically lower than that for 2006 ($P < 0.001$ for both years). In contrast, the mean score for 2005 was statistically lower than the mean for 2006 on the Vessels midterm ($P < 0.001$), whereas no statistical differences were found between mean midterm scores for 2004 compared with 2006 on this module (GI/Liver: $F = 30.79$, corresponding P value of <0.001; Renal: $F = 15.76$, corresponding P value of < 0.001; Vessels: $F = 15.45$, corresponding P value of <0.001).

Figure 3 displays average test scores for the final exams for years 2001–2006. The average score for the 2006 exams was 8–14 points higher than for any prior exam, a result that is statistically greater than the mean for all other years ($P < 0.001$ for all years). For all years considered, the highest mean score for the final exam was seen in 2006, a result that

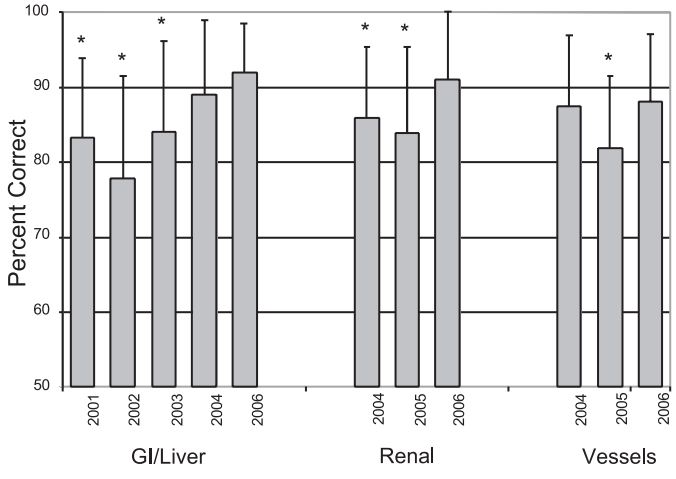

Fig. 2. Mean (±SD) percent correct answers on the midterm exams for Gastrointestinal (GI)/Liver, Renal, and Vessels sections. *Years with mean test scores statistically below that for year 2006. Years in which the midcourse exam content was presented in a sequence that was not the same sequence as that of 2006 are not included.

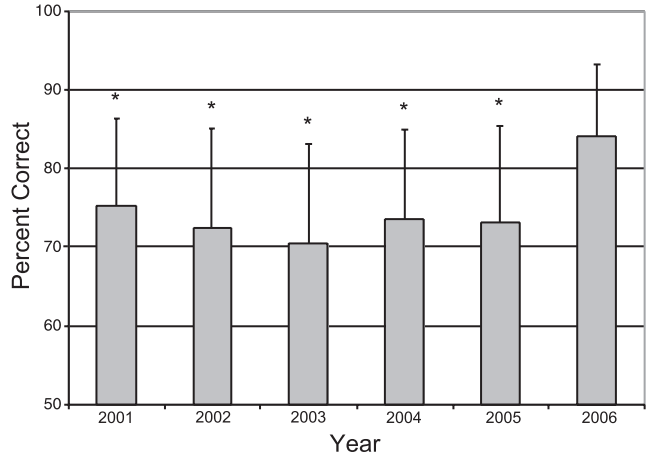

Fig. 3. Average (±SD) percent correct answers for the final exam for years 2001–2006. *Years with mean test scores statistically below that for year 2006.

is statistically higher than the mean final exam scores for all years between 2001 and 2005 (overall $F = 14.44$, $P < 0.001$ for all years versus 2006 via the Bonferroni multiple-comparison test).

Descriptive Assessment of Survey Results

One hundred sixteen of the 120 medical students completed a course evaluation. The evaluation questions and the student responses included the following:

1. Did you feel there was adequate teaching/contact time with the faculty?
Yes (91%).
2. How well did you learn the material when:
A. You presented the material.
Extremely well or very well (84%).
Adequately (11%).
Poorly (3%).
No response (2%).
B. Another team made the laboratory presentation.
Extremely well or very well (47%).
Adequately (41%).
Poorly (9%).
No response (3%).
3. Rank the overall effectiveness of the course.
Outstanding (45%).
Very good (43%).
Adequate (8%).
Poor (2%).
4. Provide general comments on the strengths and weaknesses of the course (representative sample).

- This course was excellent. It should be an example of how to incorporate technology into improving our education.
- Overall, I loved histology. A refreshing shift from the type of thinking that we do in lecture, and I found the various teaching methods to be great. I would make it easier for students to post their group presentations because some of them were phenomenal teaching aids. Overall, I thought the teaching was great.
- I know it can only get better with time, but I was frustrated that all the slides on-line were "textbook slides" that had very good examples of everything. This would not be the case if we were using real microscopes, as it was not the case for the final exam.
- It really was wonderful, much better than looking through the microscopes. Everyone gets the same idea of what a certain type of cell is rather than the professor coming around to each microscope to confirm on slides that are not as well preserved. Much more efficient, as well.

Faculty Comments

The following comment was from the Director of the second-year histopathology program:

> Students have a significant experience with microscopic histopathology as part of their pathology training in Year 2. Several informal discussions with pathology faculty have revealed that they feel that students have come to the initial pathology laboratories better prepared than they were in the past (before the introduction of team-based learning made possible through the use of virtual microscopy) and that they are less intimidated by the histopathology exercises.

The following comment was from the Director of the first-year Histology course (an author of this article):

> One of the most striking changes in the teaching of Histology using the techniques employed in this study has been the marked increase in class attendance. Where we had previously lectured in a lecture hall with a depressing 50% of the class in attendance, as well as microscopy labs just half full, we now had almost 100% attendance in our virtual microscopy lab sessions. Previously, an appreciable number of students felt they could get all the lecture material they needed by watching lectures, which were available on-line. Also available to students was an annotated computer database of all microscope slides that had been scanned and saved as static images. It had been assumed that the availability of these substantial study aids was the reason for the poor attendance in lecture and microscope labs.
>
> However, even with these comprehensive learning aids still readily available, our new format of instruction resulted in lab attendance that approached 100% of the class. We believe key reasons for this change were:
>
> *1*. Team assignments and presentations. These activities encouraged active participation by presenters and audience. The presentations were for the most part lively and enthusiastically delivered, often with considerable humor. The presentations allowed students to assess their understanding of key topics and to integrate physiology and histology.
>
> *2*. Short, graded on-line lab quizzes taken by lab teams. The quizzes were not meant to be overly difficult. Students received immediate feedback, receiving their scores at the end of the quiz. A successful quiz grade indicated that objectives of the e-lecture and lab had been met.
>
> *3*. Concise lab "reviews" or "overviews" delivered by TAs or faculty. These reviews included presentation of pathologies relating to and compared with the 'normal' histology covered in the lab section, as well as a chance for the students to ask follow-up questions concerning clinical applications.
>
> Faculty reaction to student enthusiasm and activity was considerable. Seeing a room full of bright and interested faces proved to be extremely gratifying! This should help considerably in recruiting future teaching faculty.
>
> The final Histology exam involved student identification of a series of 30 unknown slides. This allowed faculty a previously inaccessible view of the methods students use when they approach and examine unlabeled material. When students are bent over a microscope, there is no way of knowing how they are investigating each slide. However, with virtual microscopy, each student's computer screen is in clear view; watching this investigative process provided faculty with a clearer understanding of how students analyze and review slides.

DISCUSSION

This study assessed the educational effectiveness of team-based learning, asynchronous content distribution, and virtual microscopy (2, 6, 14, 16) in the first-year Histology course at The Johns Hopkins School of Medicine. Many components of this study led to improved test scores: virtual slides, team-based learning environments, increased faculty/student contact time, standardization of content, and increased student participation in class and at home. Virtual microscopy was the learning component that made the other phases of the course possible. It was not the purpose of this article to examine which of these changes had the greatest impact on improving student

test scores, but rather to show that integrating all of these changes led to better retention of knowledge as measured by exam scores. Demonstrating which facets of overall instruction led to these improvements would involve the development of a controlled scientific test whereby one component of the curriculum is changed while all other components are held constant, a resulting experiment that is neither practical nor ethical given the demands of medical school education.

The benefits and weaknesses of using virtual microscopy in teaching histology included the following.

Benefits

1. Student discussions permit faculty members to focus on links between histology, physiology, and pathology.

2. Digital slides permit content to be standardized. The problem of maintaining a satisfactory collection of glass slides due to breakage of irreplaceable content or to sections that have become suboptimal over time is eliminated.

3. Slides are easily annotated to help students establish a deeper understanding of the material.

4. Students are able to scroll, magnify, and take snapshots of images for their notes or class presentations.

5. Students are able to view and review slides at any time. Records show that virtual microscopy was used most heavily between the hours of 4 PM to 1 AM, and times of 4 AM were recorded on several occasions.

6. Students are exposed to technology and, perhaps, to the principle method of content distribution in future clinical settings.

Weaknesses

1. The startup costs for virtual microscopy can be considerable: computer workstations as well as a server must be available, and slides must be digitized. This expense is somewhat mitigated by the costs associated with microscope maintenance.

2. There is no feature in the Neuroinformatica application that allows students to focus the virtual microscope. This impacts the teaching of histology in two ways: all scans must be of thin sections (due to a limited depth of field of scanned imagery) and students must be afforded the opportunity to learn techniques of traditional microscopy in other ways. We intend to provide this exposure to light microscopy in future versions of the course by maintaining an island of conventional microscopes in each laboratory and requiring that students complete a glass slide assignment during the course.

Conclusions

In summary, students ranked this year's Organ Systems Histology course as one of the top courses taken during the first-year program, a far superior ranking than in previous years. Many students have explicitly urged the faculty to apply the same active teaching techniques used in the Histology course to the other courses offered throughout the year. The use of virtual microscopy and team-based learning as described in this report has permitted the faculty to make major strides in the delivery of course content and to better integrate histology and physiology.

ACKNOWLEDGMENTS

The authors thank Drs. Ann Hubbard, Peter Espenshade, and Doug Murphy for assisting with the development of the prelaboratory lectures; Susan Mrozowski for tireless administrative support, and Doug Hoppes for technical support. Thanks also go to Dr. Richard Thompson for the assistance with the statistical analysis of the data.

REFERENCES

1. **Adobe.** *Adobe Acrobat Connect Professional.* http://www.adobe.com/products/acrobatconnectpro/?sdid=HCSB [2 July 2007].
2. **Anderson WL, Mitchell SM, Osgood MP.** Comparison of student performance in cooperative learning and traditional lecture-based biochemistry classes. *Biochem Mol Biol Educ* 33: 387–93, 2005.
3. **Ben-Jacob MG, Levin DS, Ben-Jacob TK.** The learning environment of the 21st century. *Int J Educ Telecommun* 6: 201–211, 2000.
4. **Bradley P.** The history of simulation in medical education, and possible future directions. *Med Educ* 40: 254, 2006.
5. **Gu J, Ogilvie RW.** *Virtual Microscopy and Virtual Slides in Teaching, Diagnosis, and Research*. Boca Raton, FL: CRC, 2005.
6. **Koles P, Nelson S, Stolfi A.** Active learning in a year 2 pathology curriculum. *Med Educ* 39: 1045–1055, 2005.
7. **Lu J, Pan Z, Lin H, Zhang M, Shi J.** Virtual learning environment for medical education based on VRML and VTK. *Computers Graphics* 29: 283–288, 2005.
8. **MBF Bioscience.** *Products for Stereology, Neuron Tracing, Brain Mapping.* http://www.mbfbioscience.com [2 July 2007].
9. **Rogers D.** A paradigm shift: technology integration for higher education in the new millennium. *AACE J* 1: 19–33, 2000.
10. **Rushton A.** Formative assessment: a key to deep learning? *Med Teach* 27: 509–513, 2005.
11. **Stata Corporation.** *Stata Statistical Software: Release 9.0*. College Station, TX: Stata, 2005.
12. **TechSmith.** *TechSmith Camtasia Studio*. http://www.techsmith.com/camtasia.asp [2 July 2007].
13. **Valcke M, De Wever B.** Information and communication technologies in higher education: evidence-based practices in medical education. *Med Teach* 28: 40–48, 2006.
14. **van Aalst J.** Rethinking the nature of online work in asynchronous learning networks. *Br J Educ Technol* 37: 279–278, 2006.
15. **Van Sint Jan S, Hilal I, Salvia P, Sholukha V, Poulet P, Kirokoya I, Rooze M.** Data representation for joint kinematics simulation of the lower limb within an educational context. *Med Eng Physics* 25: 213–220, 2003.
16. **Vonderwell S.** Factors that influence participation in online learning. *J Res Technol Educ* 38: 213–230, 2005.
17. **Wacom.** *Wacom Homepage*. http://www.wacom.com/index2.cfm [2 July 2007].