Virtual microscopy in the undergraduate teaching of pathology

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INTRODUCTION

In the last 20 years, web-based resources developed to supplement or replace the traditional methodologies have expanded dramatically. These resources have shown clear benefits, as classes can be delivered to many students simultaneously, and this has helped medical schools to train in a more cost-effective way.[1]

Histology and pathology play an essential role in education in undergraduate courses in medicine. The practical knowledge of these disciplines has classically been delivered using glass slides and conventional microscopes (CM), as web-based resources were limited to static images, which were very different from real practice. Virtual microscopy (VM), also referred to as whole slide imaging, has recently started to change the
way in which these disciplines can be delivered online by providing the ability to scan entire glass slides at diagnostic resolution. A digital slide of the tissue section is created and with the use of specific software can be viewed and magnified in real-time across the web very much like using a CM. Currently, several commercially available systems can digitize glass slides containing tissue sections and produce virtual slides of excellent quality. The rapid progress of this technology and its many potential benefits will probably result in a progressive shift from conventional to VM in routine diagnostic pathology.\[2-4\]

Several studies have documented the success of VM in graduate education in medical,\[5,6\] dental,\[7,8\] and veterinary schools.\[9-11\] However, although VM has been used for many years in the US, reports on the experience with this technology in the undergraduate teaching of pathology are still limited and there is little evidence about its true impact on students’ knowledge and study habits.

In this study, we report the experience in the transition of a General Pathology course in the medical school of the University of Barcelona from practical teaching based on CM to a new format in which this tool has been totally eliminated, and all microscopy work is conducted on the computer using VM. We specifically aimed: (1) To assess the students’ impressions regarding the impact of VM on their learning and to objectively assess the success of implementing this new technology in their curriculum; (2) to determine whether moving from glass to virtual slides has an impact on student scores in practical exams of pathology; and (3) to evaluate the changes in study habits associated with the introduction of this tool in undergraduate teaching.

**METHODS**

The study was conducted in the Department of Pathology of the School of Medicine in the University of Barcelona, Spain. This university implemented the open-source course management system modular object-oriented dynamic learning environment (Moodle) in 2004, and all the supporting information and most of the activities of each discipline are available to the students in this platform.

The action was conducted in General Pathology, which is delivered in the 3rd year as a 4-month course and has 6 European Credit Transfer System credits.\[12,13\] Two different groups take the discipline each year, the first group from September to January and the second from February to May. All the students in both groups had previously had a whole year of experience using CM in the course of histology, but none had had any previous experience with VM. During the 2013–2014 course, one group studied anatomical pathology using CM whereas the second group used VM.

**Characteristics of the Conventional Microscopy Course**

This group took the discipline from September 2013 to January 2014 using CM, following the same rules established in the previous 5 years. The group was divided into six smaller groups each composed of 15 students. Two practical classes were scheduled during the course, each of which included 16 histological slides stained with hematoxylin and eosin, being representative of basic pathological lesions. Eighteen sets of slides including consecutive sections of the 16 cases were available for the use of the students in each practical class. Practical classes of 2 h in duration were delivered in the microscopy room of the medical school and were conducted by a professor of pathology. The professor briefly showed the most relevant features of each particular slide with a microscope connected to a video camera and several screens. Thereafter, each student had a set of the slides for his/her use and had 90 min to observe the slides on his/her own single-headed microscope with the support of the faculty member, who solved all the questions and problems brought up by the students.

**Characteristics of the Virtual Microscopy Course**

This group took the discipline from February to May 2014 using only VM. The practical course included the same 32 cases used in the previously described group. The group was divided into six smaller groups each composed of 15–16 students. A single practical class was scheduled at the beginning of the course (February). The class was delivered in a room equipped with a computer with internet connection and a 52-inch screen and was conducted by a faculty member, being of 1/2 h in duration. The professor briefly showed how to access to the website, the general characteristics of the navigator and how to retrieve the supporting information. After this initial session, all the students were allowed to access the virtual slides any day and at any time from any computer connected to Internet. The students were given the opportunity to contact their tutors for any problem or doubt encountered when observing the slides on their computers.

**Virtual Slides, Navigation and Supporting Files**

All the cases were digitized in a VENTANA iScan HT (Roche-Ventana Medical Systems, Tucson, AZ, USA) at a magnification of \(\times 20\). The system creates high-resolution digital images of tissue sections. All files were stored on a server hosted at the Spanish Division of Roche Diagnostics. The students access the virtual slides through a hyperlink on the Moodle platform, using their own computers as virtual microscopes. The images are viewed in the Virtuoso viewer (Roche-Ventana Medical Systems, Tucson, AZ, USA), which works as a web browser and simulates a CM [Figure 1]. Virtuoso is designed to organize the images into different cases and the cases into groups. No specific
Two supporting pdf files were posted on the main page of the discipline in the Moodle platform. One included general information to guide student access to the viewer and the username and password necessary to access to the website. The second pdf file included educational text discussions for each particular case.

**Online Evaluation of the Skill Level**

An online quiz was performed to evaluate the skill level reached by the students in the evaluation of the microscopic lesions. A question bank containing 200 multiple choice questions was created in the Moodle platform. All questions were based on static microphotographs prepared by the faculty by selection of specific areas from the same 32 glass slides included in both practical classes and had 5 possible answers. All the questions only had one correct answer qualified with a mark of +1. Each wrong answer was qualified with a mark of –0.25. For the examination, 40 questions were randomly selected from the pool. The test was available on the Moodle platform during a 24 h period. Both the order of the questions, as well as that of the answers was automatically distributed randomly for each student, thus, questions and answers were presented in a different order to every student. There was a 20 min time limit to complete the exam.

**Audit of Student Access to the Virtual Slide Viewer**

For the VM course, the viewer registered any access to the virtual slides by any of the students. This registration was performed anonymously, as all the students logged in using the same login and password. The day and time of any single accession, as well as the time spent by the student on each slide, were registered, and a pdf file was created with all the information.

**Voluntary Student Survey**

At the conclusion of the VM course, a voluntary survey was undertaken by the students to assess the students’ impressions regarding the impact of VM on their learning and the success of implementing this new technology in their curriculum. The survey was designed using the free website https://www.surveymonkey.com (SurveyMonkey®, Menlo Park, CA, USA) and was posted as an online hyperlink on the Moodle platform, which remained open for a whole week after the online exam was completed. Questions were related to the quality and easiness-of-use of the software and navigation, VM versus CM, supporting information, introduction of the activity by the professor and an online quiz [Table 1]. The student survey was designed as a Likert-scale questionnaire with a five-point scale with the following options: Strongly agree, agree, undecided, disagree, and strongly disagree. Ethical clearance was granted with participation in evaluations being entirely voluntary and completely anonymous.

**Data Analysis**

Statistical analysis was performed using the SPSS (version 18.0; SPSS, Inc., Chicago, IL). The results are presented as absolute numbers and percentages or mean and standard deviation. The analysis was mostly descriptive and included Chi-square tests.

**RESULTS**

**Characteristics of the Groups**

The CM course had 88 students, 67.0% (59/88) females and 33.0% (29/88) males, with a mean age of 20.6 ± 1.4. The VM course had 93 students, 68.8% (64/93) females and 31.2% (29/93) males, with a mean age of 20.8 ± 1.3. No differences were observed between the two groups.

**Characteristics of the Virtual Slides**

The size of the files ranged from 149,321 to 1,851,049 Kb (mean 751,562.7 ± 413,330.2 Kb). The total weight of the 32 files was 24,050,005 Kb. The scanned images can be viewed up to a magnification of ×400 and are always in focus, with optimized contrast and adjusted illumination. At high magnifications it is easy for the student to maintain orientation with respect to the entire section, because the system indicates the position of the slide on a thumbnail showing a small representation of the section [Figure 1].

**Online Evaluation of the Skill Level**

The mean mark in the online test in the CM course was 9.87 ± 0.34 (range: 8.3–10), with all the students passing the exam. Seventy-six out of 88 (86.4%) answered all the questions correctly. The mean mark in the VM course was 9.86 ± 0.53 (range: 6.7–10) with 91/93 students (97.8%) passing the online test. Eighty-five out of 93 (91.4%) answered all the questions correctly. No differences were observed between the two groups (P = 0.880, Student’s t-test).
Audit of Student Accesses to the Viewer
The number of visits to the VM from the opening of the website to the day of the exam is shown in Figure 2; about 80.3% of the accesses (862/1073) were done in the week prior to the examination; 57.5% of the visits were made on holidays and 42.5% on working days. The times of access during the day are shown in Figure 3. The earliest access was at 8:33 am and the latest at 00:55 am, with 58.1% of the visits being observed between 8:00 am and 6:00 pm and 41.9% later than 6:00 pm. The mean length of the students’ accesses was 4 min 2 s. Thus, the overall time spent by the students on studying the 32 slides included in the course (including the 30-min time of the initial presentation of the website) was 2 h 50 min.

Student Survey
Sixty-one out of 93 (65.6%) students participated in the survey. Table 1 shows the questions included in the survey and the students’ answers, and Figure 4 shows the mean students’ ratings for the main items of the survey concerning the use of VM; 86.6% of the students found the software friendly, easy-to-use and effective for the purposes of the course. The most appreciated feature of VM was the possibility to access the images anywhere and at any time (93.3%), and 71.6% of the students thought that navigation with the virtual was easier than with glass slides. Although a significant percentage of the students were neutral to both methods, most (50.8%) preferred VM to CM.

Consequences on the Workload for the Faculty Staff
The workload in terms of time in classroom teaching for the faculty staff was reduced from 20 h to 2.5. None of the students required faculty assistance. No questions to the tutors were registered in relation to problems or doubts encountered when observing the slides on their computers.

CONCLUSIONS
The results of this study confirm that VM can effectively replace CM to teach pathology in undergraduate courses in medical schools and show that the microscopic skills acquired with VM are comparable to those acquired with CM, the classical tool for teaching pathology. The overall feedback from the students was highly positive. Students complemented the ease of use of the software. Students felt they worked faster with VM, and over 70% thought that the navigation with the VM was easier than with the CM. The most appreciated feature of VM was the possibility to access the images anywhere and at any time.

Table 1: Student’s responses to the survey regarding the use of virtual and the conventional microscope

<table>
<thead>
<tr>
<th>Questions included in the student’s survey</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The software is friendly, easy-to-use and effective for the purposes of the course</td>
<td>43.3</td>
<td>43.3</td>
<td>10.0</td>
<td>3.4</td>
<td>0</td>
</tr>
<tr>
<td>The access to the virtual slides is quick</td>
<td>21.7</td>
<td>53.3</td>
<td>13.4</td>
<td>8.3</td>
<td>3.3</td>
</tr>
<tr>
<td>I liked the possibility to access the images anywhere and at any time</td>
<td>65.0</td>
<td>28.3</td>
<td>5.0</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>The quality of the image of virtual slides is adequate</td>
<td>26.7</td>
<td>38.3</td>
<td>21.7</td>
<td>8.3</td>
<td>5.0</td>
</tr>
<tr>
<td>VM allows time saving</td>
<td>31.2</td>
<td>44.3</td>
<td>21.3</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>The identification of cells and structures with VM is easy</td>
<td>6.7</td>
<td>41.7</td>
<td>38.3</td>
<td>10.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Navigation with the VM viewer is easier than with glass slides</td>
<td>33.3</td>
<td>38.3</td>
<td>26.7</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>I had problems with the navigation</td>
<td>3.3</td>
<td>13.3</td>
<td>15.0</td>
<td>31.7</td>
<td>36.7</td>
</tr>
<tr>
<td>The presentation of the virtual viewer and the slides by the professor is useful</td>
<td>6.7</td>
<td>26.7</td>
<td>33.3</td>
<td>16.7</td>
<td>16.6</td>
</tr>
<tr>
<td>The presentation of the virtual viewer by the professor is unnecessary</td>
<td>21.7</td>
<td>6.7</td>
<td>35.0</td>
<td>18.3</td>
<td>18.3</td>
</tr>
<tr>
<td>The supporting material (pdf document) is useful and adequate</td>
<td>73.8</td>
<td>21.3</td>
<td>4.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The test based on image captures is a good way to evaluate the knowledge acquired with VM</td>
<td>14.7</td>
<td>57.4</td>
<td>18.1</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>I prefer virtual to CM</td>
<td>21.3</td>
<td>29.5</td>
<td>34.4</td>
<td>11.5</td>
<td>3.3</td>
</tr>
<tr>
<td>I prefer conventional to VM</td>
<td>1.6</td>
<td>13.1</td>
<td>42.6</td>
<td>23.0</td>
<td>19.7</td>
</tr>
</tbody>
</table>

The figures indicate percentages, VM: Virtual microscopy, CM: Conventional microscopy.
time. This finding was highlighted by data obtained from
the audit of accesses to the navigator, showing that over
half of the accesses were made on holidays, and over
one-third were made after working hours. Finally, the
introduction of VM resulted in a significant reduction
of the workload for the students and for the faculty staff
of pathology in terms of classroom teaching, although
there was a significant increase in the time related to the
preparation of the material. Interestingly, the transition
from conventional to VM was not a gradual process, but
a sudden change, showing that positive results may be
immediate.

Curriculum reform in medical schools worldwide has
focused on a reduction in contact hours to decompress
crowded programs, an emphasis on independent learning,
and on the development of interpersonal skills and
problem-solving abilities. Achieving this objective has
inevitably meant that time has been reallocated from
traditional areas to new educational activities deemed
to be more important. In some medical schools, this has
led to curricula that offer diminished opportunities for
students to learn the basic medical sciences. In this
context of standardized curricula and the growing number
of medical students, new strategies have been employed
to improve the student experience of learning pathology.
The introduction of VM, an adequate alternative to the
traditional methods of teaching pathology, can help the
students to achieve a satisfactory knowledge of these basic
disciplines in these newly reformed curricula. Our results
showed no differences in the exams between the VM and
the CM groups, plus the overall favorable feelings of the
students about VM are in keeping with the adequacy of
this tool for students is that the slides are always in focus,
with optimized contrast and adjusted illumination. Indeed,
over 70% of the students thought that the navigation with
the VM viewer was easier than with glass slides.

The anonymous survey showed that the students found
VM useful. Our results are in keeping with previous
reports showing that the students’ experience with VM
is very favorable. This provides clear evidence of the
learning benefits derived from using this tool. VM allows
students to independently explore the entire histological
slide, as well as control the content and its rhythm of
delivery. As observed in previous studies, this
interactive technology makes microscopic laboratory
studies in pathology more efficient and teaching resources
more portable and independent of class schedules. As
shown in our study, according to the students, the most
appreciated feature of VM was the possibility to accede
to the images anywhere and at any time. Indeed, data
obtained from the audit of accesses to the navigator
showed that over half of the accesses were made on
holidays and over one-third were made after working
hours. The adoption of electronic course materials,
along with almost universal use of personal and laptop
computers by the medical school students facilitates the
introduction of VM.

Although the initial equipment and software cost for
creating VM is high, this new technology has the potential
to revolutionize the way individuals teach and learn from
microscopic images. With VM, the most representative
slides with the best quality material can reassuringly be
included in teaching sets. Not only can such materials
be easily added to the virtual sets, but compared with
glass slides these digital slides will not fade, break, or
disappear. Scanned slides for dedicated teaching should
be de-identified prior to making them available for
general users. One of the main advantages of VM is the
portability (time and location), and ease of maintenance.
Finally, this tool may allow reducing or even eliminating
the expensive laboratories of microscopy.
The main strength of our study is that it allows adequate comparison of two very similar groups from the same course working with the same material and that it provides objective data on how students learn pathology. A possible limitation of our study is the use of an examination system restricted to standard static images. However, this allowed comparison of the results with the CM group, as all the image captures were made from the same cases. Examinations that apply virtual technology require more sophisticated management software. Finally, the very good results obtained in the examinations should be considered as the consequence of the extremely high marks required in Spain to accede to the medical schools.

In conclusion, evidence showing that the microscopic skills achieved by students with VM are comparable to these acquired with CM indicates that this technology can effectively replace the traditional methods of learning pathology. One of its main advantages is that it provides mobility and convenience to medical students.

REFERENCES