Learning across disciplines using virtual microscopy: new approaches

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We have been using virtual microscopy for learning and teaching microscopic morphology since 2003. Initially trialled in demonstrator-supported classes in histopathology, we now use virtual slides in a variety of cross-disciplinary learning and assessment activities across the Medicine program, requiring linkage between histology, histopathology and clinical manifestations. More recently, we have successfully collaborated with colleagues in Botany and Zoology to extend the use of virtual slides to introductory biology and ecology classes. A repository of virtual slides, selected for their suitability for teaching across all of these disciplines, has been developed. To increase the educational value of virtual microscopy, we have collaborated with colleagues in Computer Science to create adaptive tutorials, which embed virtual slides within an interactive environment that includes self-assessment items. We are progressively expanding the use of these self-study modules across different disciplines, to improve the learning experience for all of our students who use virtual microscopy.

Keywords virtual microscopy; multidisciplinary learning and teaching; assessment

1. Introduction

Virtual microscopy has been at the heart of a "quiet revolution" in learning and teaching, especially in disciplines such as Histology and Pathology. A key enabling technology for students who have limited aptitude for traditional microscopy, virtual microscopy can be used effectively at a variety of different levels of expertise. This innovative technology thus increases student engagement, facilitates learning and teaching for the increasingly diverse student body, and improves student satisfaction with microscopy-based classes.

One of the earliest successful implementations of virtual microscopy-supported learning and teaching was at the University of Iowa [1,2]. With the support of the US National Library of Medicine, Prof Fred Dee developed the virtual slideboxes of histology and histopathology, which are available on-line at http://www.path.uiowa.edu/virtualslidebox/. At the University of New South Wales (UNSW), we immediately recognised the potential of virtual microscopy in learning and teaching as well as in assessment, so in collaboration with Prof Dee we moved to implement its use on an even larger scale. Initially, we progressively replaced glass slides with virtual slides in all Pathology practical class activities for both Medicine and Science students, then extended the use of virtual microscopy to Histology and to cross-disciplinary classes, while investing substantially in the development of appropriate computer teaching laboratories. Most recently, we have collaborated with colleagues to extend, for the first time, the use of virtual slides to the disciplines of Botany and Zoology.

In this review, we will discuss the various challenges we have faced, the numerous tricky problems we have encountered, and the many successes that have made it all worthwhile.

2. Approaches to using virtual microscopy

Virtual microscopy can be used in quite different ways depending upon curriculum design, constraints on class time and the desired learning outcomes. At many institutions, virtual slides are used primarily for self-study, either as preparation for a class or as a resource for independent study/revision. At UNSW, we initially introduced virtual microscopy for teaching in our Medicine degree program. Our timing was fortunate, because this occurred almost simultaneously with a planned major review and reform of the Medicine program. Thus it was possible to restructure the design of practical classes around the availability of virtual slides, and to invest in the refurbishment of traditional microscopy laboratories as dedicated computer-based teaching areas. In effect, we replaced glass slides with virtual slides in modified "traditional" classes, which used case studies to provide the focus for discussion of relevant slides.

This allowed us to retain the benefits of our existing investment in structured worksheets built around clinical problems, with learning objectives for each class and extensive supporting materials, including clinical and radiological images, results of investigations, etc. At the same time we were able to take full advantage of the benefits offered by virtual microscopy. Notably these included gains in: (i) active student engagement, because students did not lose orientation while examining sections, while our policy of having two students share one computer workstation promoted discussion and collaborative learning; and (ii) efficiency, because it was feasible to cover more slides in less time, so even though curriculum reform mandated some decrease in the total number of practical classes, we actually gained in terms of the breadth and depth of microscopy coverage. Importantly, we did not reduce the number of
demonstrators in the class, but were instead able to enhance the quality of the interaction between students and
demonstrators, a consideration of particular importance in classes of 130-140 students (i.e. up to 70 client computers).

Of course we also provided students with password-protected access to our collection of virtual slides for
independent study, e.g. via the campus-wide wireless network or a broadband connection at home. As at other
institutions, the take-up of this additional option for private study was high, especially around examination times!

3. Virtual microscopy across disciplines in the classroom

3.1 Virtual microscopy in cross-disciplinary learning and teaching in Medicine

As noted above, in the Medicine program we redesigned practical classes around the availability of virtual microscopy.
The simplicity and convenience of this technology made it possible for us to incorporate examination of virtual slides,
with changing emphasis and increasing complexity/detail, in classes offered to students in all three phases of our 6-year
undergraduate Medicine degree.

More importantly, we emphasised cross-disciplinary learning in these classes. Thus in Phase 1 (year 1/2) classes we
radically restructured practical classes to provide simultaneous teaching of normal histology and histopathology, in a
clinical context. This involved team teaching by staff from Anatomy and Pathology, with an emphasis on the value of
understanding the normal in order to be able to explain abnormalities. Appropriate structured worksheets were
developed for these new classes. Not all topic areas were suitable for cross-disciplinary classes, but wherever feasible,
and within the constraints of the clinical scenarios used as a focus for learning across a 2-3 week period, we gave
priority to this approach. We provided case studies related to (but distinct from) the scenarios, so that learning was in a
clinical context. For example, in a class on the heart, we showed virtual slides illustrating normal myocardium and
valves, followed by a case study with virtual slides of myocardial infarction. Similarly, in a class on the respiratory
tract, we showed slides illustrating normal airways and lung tissue, as a precursor to discussing the tissue changes and
approach to diagnosis of pneumonia.

In Phase 2 (year 3/4) classes our focus was not so much on integration between basic sciences, but rather on bridging
basic sciences to clinical practice. Therefore we designed classes around clinical presentations/clinical problems, which
helped students to understand pathogenesis and illustrated diagnostic strategies. These involved cross-disciplinary
integration with Medicine/Surgery and various subspecialities, with the different elements of laboratory medicine, as
well as with Radiology/Diagnostic Imaging.

While Phase 3 (year 5/6) of our Medicine program primarily involves clinical rotations, we have recently introduced
a selective module on the rational use of investigations in clinical decision-making. This module has a major focus on
laboratory medicine, including the interpretation of biopsy reports. Students undertaking the module learn about the
complexities of diagnostic reporting by attempting to approach cases from the perspective of the pathologist, including
examining virtual slides independently, as well as glass slides at a multi-header microscope with guidance from a
specialist histopathologist.

Students responses to all of these cross-disciplinary classes have been, without exception, extremely positive. We
have previously reported in detail about the effectiveness of the Phase 1 cross-disciplinary classes in Anatomy and
Pathology [3].

3.2 New opportunities for virtual microscopy in learning and teaching

A great deal of the early development of applications of virtual microscopy in learning and teaching has been the result
of innovations by teachers in Pathology [4] and Anatomy/Histology [5]. Of course these are by no means the only
disciplines in which microscopic examination of tissues can contribute to a student's learning. At UNSW,
Botany/Ecology and Zoology have long made use of microscopy in classes, although lack of technical support and the
cost of replacing damaged teaching slides had led to declining use of this approach in recent years. We collaborated
with colleagues in these disciplines to generate a useful set of virtual slides for teaching (as part of the UNSW Virtual
Slide Repository, described in more detail in section 5) which not only allowed such classes to be resuscitated but also
facilitated the introduction of additional innovative teaching sessions.

The impact of these has been remarkable. In Botany/Ecology, the ready availability – for the first time – of tissues
from specimens collected from a range of species and environments facilitated teaching about adaptation and
diversification. The use of virtual slides was highly rated students, with mean questionnaire ratings above 4 (on a scale
from 1 to 5) for effectiveness, quality of images, ease of use and capacity for promoting discussion. Remarkably, over
80% of students described virtual slides as "fun" and almost 90% rated using them as better than traditional microscopy.
Perhaps more importantly, the benefits extended to measurable learning outcomes. When students' performance in
selected assessment tasks was compared, there was a statistically significant improvement in the marks obtained in a
virtual slides practical as compared to a traditional practical (P <0.0001) (Dr Stephen Bonser, personal communication).

An unexpected benefit of the use of virtual microscopy in Biology classes was that immediately after its introduction,
the technology enabled a vision-impaired student to undertake the first year subject Evolutionary and Functional
Biology. This course has a significant practical component, which in the past was based entirely on conventional microscope slides, and the student would otherwise not have been able to enrol.

4. Technical considerations and problems

4.1 Support

The technical issues surrounding the introduction of virtual microscopy into classroom teaching are not trivial, especially when catering for a large number of client computers making simultaneous demands on the server. It is impossible to overemphasise the importance of high quality technical support in achieving successful implementation. At UNSW we have been exceptionally fortunate to have the active involvement of the team in the Medicine Computing Support Unit to deliver virtual microscopy in high-use classroom environments. These colleagues have played a major role in the provision of appropriate server hardware, overcoming issues with viewer and database software, ensuring that our system performs satisfactorily in a high-speed networked environment, and contributing to further development.

4.2 File formats

Early implementations of virtual slide technology used FlashPix (*.fpx) and Zoomify (*.pff) file types, but not all web delivery software can display slide files in these formats. At the time of writing, the de facto standard is the Aperio (*.svs) format. This is a pyramidal tiled TIFF file, which holds image data for different magnifications in different layers. Some web delivery software for virtual slides requires that rather than storing the image data in a single file, the different magnification layers (or even the individual tiles) are stored as separate images in a directory. Files in the Aperio format can readily be converted to such composite virtual slides, which may be more readily accessed remotely without the use of special viewer software. Conversion between file formats may become a relevant issue as web display technology continues to develop e.g. the Deep Zoom (*.dzi/dzc) format of Microsoft Silverlight applications has potential for virtual slide display, as does the Google Maps application programming interface.

4.3 Web server response

The capacity of web server software to respond quickly to multiple clients (in our case, as many as 70 computers simultaneously accessing a particular virtual slide file) is a rate-limiting consideration in classroom teaching, because unsatisfactory speed of display of virtual slides has a severe negative impact on student engagement and teaching effectiveness. This situation is in quite marked contrast to that which applies when sets of virtual slides are made available as a resource for independent learning. At UNSW we initially adopted Neuroinformatica as our web server, as used at the University of Iowa, but a combination of circumstances has meant that this software is no longer being developed/enhanced for this use, and ongoing updates to versions of the Java virtual machine on client computers have created serious performance issues. We have overcome some of these via collaboration with colleagues in the School of Computer Science and Engineering at UNSW, who have developed a Neuroinformatica-compatible viewer which uses Flash rather than Java (Figure 1). Nevertheless, we are now exploring alternative web server technologies.
The Flash-based virtual slide viewer permits the user to "click and drag" and "zoom in" on the image, thus simulating the use of a real microscope exactly as in other viewer applets.

One possibility is the web server provided by Aperio, which displays *.svs files by conversion to composite web slides. However, the associated viewer uses Zoomify technology and lacks some of the features of the Neuroinformatica Java or Flash viewer, notably with respect to stepping through magnifications in a consistent manner. Performance under heavy load (>50 simultaneous client computers) has not been tested by Aperio (Aperio Australia, personal communication). Similar considerations apply to alternatives such as the Aurora web server (which handles multiple file formats) and emerging technologies such as Silverlight.

4.4 Class organisation and database management

A significant consideration when managing a large collection of virtual slides is the development of an appropriate database and a simple mechanism for creating a "class page" of virtual slides for a particular teaching session. This is built into most implementations of virtual slide web server software, but the majority allow only the creation of relatively simple web pages. Building more complex classes with links to other images (e.g. macroscopic Pathology, Radiology) or to other file types can be difficult. At UNSW, this has been addressed through the enthusiastic involvement of colleagues in the Medicine Computing Support Unit, who have developed custom software on the Lotus Domino platform.

5. The UNSW/ALTC virtual slide repository

With funding from the Australian Learning and Teaching Council, we and colleagues at UNSW have developed a repository of virtual slides for use in learning and teaching within Australian universities, particularly in Medicine and Biological Science. Specifically, the slides cover the four areas of: (i) human anatomy (histology); (ii) human pathology (histopathology); (iii) comparative anatomy/zoolgy; and (iv) plant ecology/evolution.

These sets of virtual slides are now available to educators across the sector, without licence fees or other charges, and permission is granted for the image files and their derivatives to be used within the recipient's institution, but not to be distributed via removable media or the internet. The repository is accessible at http://virtualslides.unsw.edu.au/ and registered users can view a large collection of virtual slides which are suitable for use in classroom teaching. There are approximately 150 slides in each set and these are readily searchable (Figure 2). Users can also examine sample worksheets that illustrate effective models of the pedagogies and processes involved in using virtual slides for teaching and learning.
Interested users from other countries may also obtain these sets of virtual slides, by arrangement with the Project Team that developed the repository.

6. Extending the use of virtual microscopy in learning and teaching

6.1 Interactivity in virtual microscopy

One current barrier to learning with virtual microscopy is that when working in large practical classes (as noted above, in each Phase 1 Medicine class we teach up to 140 students at 70 computer workstations) it is difficult for demonstrators to provide individual assistance to all students who have difficulty interpreting microscopic morphology. Thus, despite the advantages compared to conventional microscopy, not all students are optimally engaged in learning with virtual slides. Furthermore, without expert guidance, revision of virtual microscopic material can be inefficient, leading to unremediated misconceptions. Therefore, in a collaboration with the School of Computer Science and Engineering at UNSW, we developed online Adaptive Tutorials based on virtual slides. Adaptive Tutorials are computer-based Intelligent Tutoring Systems, which create an online individualised tutorial-like experience for each student within the practical class environment, as well as a tool for revision and remediation. This innovation enables students to undertake independent exploration of virtual slides, with immediate and automated provision of adaptive feedback.

Adaptive Tutorials can be flexibly utilised: for formal in-class teaching or for later review with a demonstrator; for individual or collaborative use by students; or for formative (or even summative) assessments. For example, students' conceptions of the relationship between microscopic structure and function can be efficiently diagnosed and, if necessary, remediated using Adaptive Tutorials. It should be noted that Adaptive Tutorials differ significantly from annotated virtual slides, which neither engage students interactively nor provide adaptive individualised feedback on their conceptual frameworks. Analysis of students' interactions with Adaptive Tutorials can also help teachers diagnose common misconceptions, permitting refinement of feedback provided by the Intelligent Tutoring System.

An example Adaptive Tutorial focusing on the topic of asthma is available to view at http://www.adaptiveelearning.com/aelp/portal/unsw/pathology/asthma (note that this requires Flash Player 10 and is best viewed at 1280 × 1024 or higher screen resolution)

Example screenshots from the tutorial are provided in Figures 3 and 4.
Adaptive Tutorials have been implemented in Phase 1 virtual microscopy classes (a cohort of more than 500), with overwhelmingly positive responses from students and teachers [6]. More than 90% of respondents found the adaptive exercises helpful, and wanted more to be made available. Over 80% of students perceived that they learned more from the adaptive exercises than from exploring Virtual Slides independently.

There is also evidence of learning benefits from Adaptive Tutorials. In a Phase 1 Medicine practical examination in 2009, a cohort of 254 students scored significantly higher (p<0.0001, Dunnett's test) on a question related to a virtual slide on cerebral infarction (“stroke”) for which an Adaptive Tutorial was available. The other topics tested in the
examination (virtual slides of asthma and metastatic adenocarcinoma in the liver) were taught using virtual slides without adaptive tutorials. It should be noted that histopathology of the brain is traditionally considered to be difficult for students, supporting the notion that the Adaptive Tutorial on that topic made a significant difference to learning.

Plans are already in place to develop Adaptive Tutorials for all Anatomy and Pathology virtual microscopy practical classes in Medicine and Science degree programs at UNSW. To enable this, we are developing a tutorial builder interface which should permit academic staff with basic computing skills to author Adaptive Tutorials.

While still in the early phases of implementation, Adaptive Tutorials based on virtual slides have the potential to revolutionise the teaching and learning of microscopy. Students’ learning can benefit from guided exploration of virtual slides with adaptive remediation. This has relevance not only to the disciplines of Anatomy and Pathology, but also Botany, Zoology and Microbiology. Wider use and controlled trials are required to fully explore the learning benefits of this innovation.

6.2 Virtual microscopy in assessment

We have successfully implemented virtual microscopy for summative assessments in Anatomy and Pathology by providing students access to password-protected index pages in computer laboratories. To ensure security, students are invigilated, and the computers are locked down to prevent access to websites other than the index page and the linked virtual slides. We have examined up to 70 students simultaneously without degradation in the loading speed of virtual slides. Furthermore, we have evidence that students perform no differently when examined using traditional microscopy as compared to virtual microscopy [7]. This method of examination is also more equitable as it eliminates the problems caused by variability between sections of tissue on glass slides. We have also found that some students who were struggling with traditional microscopy (e.g. those with visual impairment) were able to cope better when using virtual microscopy.

7. The future of virtual microscopy

The focus of this chapter has been on the use of virtual microscopy in teaching Medicine and Science students at university level. However, there is no doubt that the technology has potential beyond undergraduate teaching. When the UNSW/ALTC Repository went on line, one of the unexpected inquiries we received was from Education Services Australia, a company established by all Australian Ministers of Education which provides support for the delivery of innovative, cost-effective services across all sectors of education. As a result of our interaction with ESA, a subset of the virtual slide collections is being made available to school teachers as a classroom resource, primarily intended for use by senior high school students but potentially also relevant to junior classes. Meanwhile, at the other end of the spectrum, trainee specialist pathologists are increasingly becoming accustomed to virtual microscopy for provision of learning resources and as part of quality assurance activities. It will only be a matter of time before virtual microscopy, already part of the mainstream of learning and teaching, becomes integral to professional practice [8,9].

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References