ENHANCING THE LEARNING EXPERIENCE? A COMPARISON OF OPTICAL AND VIRTUAL MICROSCOPE LABORATORIES IN HISTOLOGY AND PATHOLOGY

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ABSTRACT
With pressure on universities to teach larger class sizes with fewer resources university teachers are increasingly looking to technology to enhance student learning. A trial comparing virtual and optical microscopes in the face-to-face teaching of histology and pathology labs was undertaken. The laboratory classes were delivered to third year Chiropractic undergraduates, studying full-time on-campus. The students were randomly allocated to either virtual or optical microscopy in their labs. Students were asked to reflect on their learning experiences with the microscopes. Data presented shows the students perceptions of their learning experiences with the microscopes, and suggests that virtual microscopes were easy to use and were used for self-directed study by students. It also suggests that while optical microscopes may promote more group discussion of histology and pathology in laboratory settings they were harder to use than the virtual microscopes.

KEYWORDS
Virtual microscopes, optical microscopes, histopathology, virtual learning experiences, student reflections.

INTRODUCTION

Microscopes are commonly used for teaching in universities. The associated capital and maintenance costs are high, however, making cheaper and more flexible alternatives attractive. Virtual microscopy (computer-based viewing of digitised microscope slides) may be a suitable alternative, but there is limited research on the impact on students' learning. Harris *et al*. (2001) compared virtual and regular [optical] microscopy classes for teaching histology to medical students and found virtual microscopic labs were a viable addition, if not a replacement, for traditional microscopy. Students gave virtual microscopy higher ratings for accessibility and efficiency, image quality. Virtual microscopy provides opportunities for strategies promoting self-directed and independent student group learning as well as more flexible access. At Murdoch University virtual microscopes were introduced in 2006. To evaluate their efficacy for teaching chiropractic students, an exploratory study was undertaken. This paper reports on a trial comparing virtual and optical microscopes in the face-to-face teaching of histopathology labs and explores the impact of virtual microscopes on students' learning.

METHODOLOGY

Third-year chiropractic students were randomly allocated to either a traditional optical microscopy (OM) group or a virtual microscopy (VM) group. All students had previous experience with using optical microscopes. The VM group used digitised versions of the class slide set delivered over a wireless local network to PC laptop computers using ImageScope software (Aperio Technologies). Due to the way the facilities were physically set up, OM students worked in groups from 1 to 10 around six Olympus ten-header microscopes, VM students worked in groups of 1-3. Each group had the same lecturer and went through the same material. At the end of semester, the students submitted reflections through a survey on their use of the microscopes and their learning.

RESULTS

Of 57 third-year chiropractic students studying pathology, 47 consented to take part in the study. Four questions in the survey related to study practices in terms of *location*, *collaboration*, *activities* and *resources*. In addition, there were open-ended questions asking students about their likes and dislikes regarding optical and virtual microscopes.

Location of study

Students were asked (Table 1): *Please identify whether you were mostly on campus, at home or elsewhere when doing activities with microscopes.*

Table 1. Location of study for the OM and VM groups

Location	**OM group** (n=25)	**VM group** (n=21)
On campus	88%	100%
At home	8%	0%
On campus and at home	4%	0%

Collaboration

Students were asked (Tables 2 and 3): *When doing activities with microscopes were you working mostly alone or with a group (please indicate the size of the group)?*

Table 2. Extent of collaboration for the OM and VM groups

Collaboration	**OM group** (n=23)	**VM group** (n=20)
Alone	9%	40%
Group	91%	60%

Table 3. Size of the collaborative groups within OM and VM groups

Collaborative group size	**OM group** (n=23)	**VM group** (n=20)
1	9%	40%
2-3	26%	55%*
4-5	17%	0
6-8	22%	0
8-10	26%	0

*One student (5%) from the virtual group identified that he was working in a group but did not specify the size of the group.

Activities

Students were asked (Table 4): *How did activities with microscopes help your understanding of the course?*

Table 4. Relationship between activities and understanding

Microscope activities	**OM group** (n=25)	**VM group** (n=21)	**Both groups** (n=46)
Linked theory with practice	72% (18)	86% (19)	79% (37)
Promoted group discussions	24% (6)	5% (1)	15% (7)
It didn't help	4% (1)	5% (1)	4% (2)

Resources

Reading beyond set texts often indicates a deep approach to learning (Biggs, 2003, p.35), so students were asked (Table 5): *If you read more than the required text please specify where you found most of your resources, e.g. web, library, lectures, WebCT supplementary materials, other people, or other.*

Table 5. Resources used

Resource	Frequency of Response	
	OM group	VM group
Web	42%	63%
WebCT materials	21%	26%
Lecturers	21%	0
Other text books	11%	0
Library	11%	32%
Other people	5%	0
Tutorials	5%	0
Microscope	0	5%

Note: More than one type of resource may have been identified by the same respondent.

Themes

As all the students had used optical microscopes in their previous two years of study the remaining questions were open ended and related to identifying likes and dislikes of optical and virtual microscopes. The results were content analysed using Microsoft Excel and manual inspection to reveal common themes. The themes are split into two major headings – optical microscopes and virtual microscopes – and are further divided into likes and dislikes.

Optical microscopes – positive themes

Both groups identified nine positive themes about the optical microscopes (Table 6).

Table 6. Positive themes identified by students about optical microscopes (across both groups)

Themes	Students %
Enhanced clarity	35%
Enhanced group work	30%
Promotes group discussions	18%
More authenticity	18%
Familiarity	8%
More teacher interaction	5%
More sense of control	5%
Superior quality of slides	3%
Gained experience using it	3%

Optical microscopes – negative themes

The students identified seven dislikes (Table 7) about the optical microscopes, notably health issues (including eye strain, headache and motion sickness) and difficulty of use.

Table 7. Negative themes identified by students about optical microscope (across both groups)

Themes	Students %
Caused health issues	40%
Difficult to use	35%
Not in control when working in groups	30%
Time consuming	15%
Missing optical slides	8%
More experience required	5%
Disliked everything	3%

Virtual microscopes – positive themes
Students identified nine positive themes about the virtual microscopes (Table 8), including ease of use, handy tools (on screen measuring tools, image capture), improved time management, and reduced health issues.

Table 8. Positive themes identified by students about virtual microscopes (across both groups)

Themes	Students %
Easy to use	63%
Handy tools	23%
Improved time management	20%
More freedom and accessibility	20%
More example slides	15%
Less health issues	13%
More convenience	10%
More examples of pathology	3%
Easier to work in groups	3%

Virtual microscopes – negative themes
Seven themes were identified (Table 9) as aspects that the students disliked about the virtual microscopes, most notably a reduction in clarity.

Table 9. Negative themes identified by students about virtual microscopes (across both groups)

Themes	Students %
Less clarity	38%
Waiting for slides to load	13%
Restricted access	13%
Inhibits group work	5%
Unreliable technology	5%
Less engagement	5%
Less authenticity	5%

The following two tables indicate positive themes (Table 10) and negative themes (Table 11) identified by each group about optical and virtual microscopes.

Table 10. Positive themes identified by OM and VM groups about optical and virtual microscopes

Theme	No (and %) of students identifying theme		
	OM (n=21)	VM (n=19)	Total (n=40)
Optical microscope			
Enhanced clarity	12 (57%)	2 (11%)	14 (35%)
Enhanced group work	9 (43%)	3 (16%)	12 (30%)
Promotes group discussions	6 (29%)	1 (5%)	7 (18%)
More authenticity	4 (19%)	3 (16%)	7 (18%)
Familiarity	3 (14%)	0 (0%)	3 (8%)
More teacher interaction	2 (10%)	0 (0%)	2 (5%)
More sense of control	2 (10%)	0 (0%)	2 (5%)
Superior quality of slides	1 (5%)	0 (0%)	1 (3%)
Gained experience using it	1 (5%)	0 (0%)	1 (3%)
Virtual microscope			
Easy to use	10 (48%)	15 (79%)	25 (63%)
Handy tools	4 (19%)	5 (26%)	9 (23%)

Improved time management	1 (5%)	7 (37%)	8 (20%)
More freedom and accessibility	5 (24%)	3 (16%)	8 (20%)
More example slides	0 (0%)	6 (32%)	6 (15%)
Less health issues	1 (5%)	4 (21%)	5 (13%)
More convenience	4 (19%)	0 (0%)	4 (10%)
More examples of pathology	1 (5%)	0 (0%)	1 (3%)
Easier to work in groups	1 (5%)	0 (0%)	1 (3%)

Table 11. Negative themes identified by OM and VM groups about optical and virtual microscopes

Theme	No (and %) of students identifying theme		
	OM (n=21)	VM (n=19)	Total (n=40)
Optical microscope			
Caused health issues	10 (48%)	6 (32%)	16 (40%)
Difficult to use	8 (38%)	6 (32%)	14 (35%)
Not in control in group work	7 (33%)	6 (26%)	12 (30%)
Time consuming	3 (14%)	3 (16%)	6 (15%)
Missing optical slides	3 (14%)	0 (0%)	3 (8%)
More experience required	2 (10%)	0 (0%)	2 (5%)
Disliked everything	0 (0%)	1 (5%)	1 (3%)
Virtual microscope			
Less clarity	10 (48%)	6 (32%)	16 (40%)
Waiting for slides to load	0 (0%)	5 (26%)	5 (13%)
Restricted access	1 (5%)	4 (21%)	5 (13%)
Inhibits group work	2 (10%)	0 (0%)	2 (5%)
Unreliable technology	0 (0%)	2 (11%)	2 (5%)
Less engagement	2 (10%)	0 (0%)	2 (5%)
Less authenticity	1 (5%)	1 (5%)	2 (5%)

The following sections reports whether both groups identified a theme (total percentage of all students identifying theme) and the percentage of students in each group (OM and VM) identifying the theme. In some cases only one group identified a theme and this is examined further in the discussion and conclusion. Example comments from students are provided for each aspect. The source of each comment is coded by type of group, gender and student number so, for example, "OF9" is Student 9 in the OM group and is a female.

Aspects students liked about optical microscopes

Optimal microscope clarity (35% total, 57% OM, 11% VM)

> The slides looked clearer and were quicker to use than the computer slides [OF9]

Group work and optical microscopes (30% total, 43% OM, 16% VM)

> The group atmosphere was probably the highlight of the optical microscopes. [OF15]

Collaboration through discussion (18% total, 29% OM, 5% VM)
Collaboration was encouraged through discussion by using the optical microscopes.

> The group discussions were the most valuable, and being walked through all of the pathology and having our questions answered by [the teacher] [OF20]

Authenticity of optical microscopes (18% total, 19% OM 16% VM)

> Give a realistic and relevant element to learning (i.e. its real tissue), Gets you to learn how to use a microscope and the problems you have with it. It not just another simulation of what generally happens (its presents the real problems / anomalies faced in microscopy. [VM5]

Familiarity (8% total, 14% OM, 0% VM)
Having previously used the optical microscopes meant some students had a sense of familiarity and comfort when using the optical microscopes. The optical group were using the optical microscopes for their laboratory work and may not have experienced the virtual microscopes.

> Comfort in using, as used one previously, a sense of familiarity. [OM3]

Teacher interaction (5% total, 10% OM, 0% VM)
Ten percent of the optical group felt that the optical microscopes improved teacher interaction.

> ...once [the teacher] comes over to the table to explain the slide, everyone can discuss together compared to Virtual Microscope which only works in pairs. It save a lot of time by explaining in a group of 7 people [OF33]

Control (5% total, 10% OM 0% VM)
A small percentage of the OM students identified being in control as important.

> I was randomly selected to be in the optical microscope (OM) lab group. Most of the time, I'm the driver while using the microscope. I have always used the OM. I find that the most beneficial thing about the OM is that I can measure the size of the exact specimen using a ruler before writing my lab report. I can't do that using the virtual or maybe i don't know how. [OF33] *(measuring is easy with VM software)*

Superior quality of optical slides (3% total, 5% OM, 0% VM)

> The quality of the slide sometimes seems better. [OF55]

Experience (3% total, 5% OM, 0% VM)

> You get experience using a microscope. [OF14]

Aspects students liked about virtual microscopes

Ease of use (63% total, 48% OM, 79% VM)
A high percentage of all students found the virtual microscope easy to use.

> I only used the virtual microscopes once. It was easy to find the right slide. There was no confusion about whether we had the right slide or not. [OF15]

> Ease of use, don't need to know how to use a microscope and since I'll never have to use one in my career that is ideal for me. [VM6]

Handy tools (23% total, 19% OM, 26% VM).

> Allowed you to identify specific areas of underlying pathology and had handy tools such as a specific view finder, which allowed higher magnification of certain aspects of the slide while others were kept at lower magnification. Comparisons between slides such as between slides containing pathology and normal slides were easier to compare [the software could display two or more slides side by side], there was no need to change a slide over or adjust anything as would normally occur when using an optical microscope [OF17]

> You can take photos of it and email to yourself (you can take it home virtually) [VM5]

VM quicker to use (20% total, 5% OM, 37% VM)
The students' ability to manage their time was thought to improve with the virtual microscope because it was quick to set-up and use with no time wasted looking for lost or missing slides.

> There was also no time wasting because of lost or missing slides. [OF15]

> It is so much easier to use than optical. You can change the magnification quickly and easily. You can zoom into the exact area you want to look at without "stuffing around". [VM13]

Freedom and accessibility (20% total, 24% OM, 16% VM)

> Easily accessible and there was no need to fiddle around with things in order to view the slide. [VF42]
>
> It would have been nice to access it from home, not only from the computers in the lab [OF55]

VM 'slides' better (15% total, 0% OM, 32% VM)

> Good slides that do not break /get dirty or stuff out. [VM5]
>
> It gives us perfectly clear images; we can zoom in or zoom out at the slides in barely 5 seconds. Not much gadgets are involved in order to get to the image piece you want. [VF38]
>
> Show each slide in really high quality and detail and allow you to study in several locations on campus. Probably the best part is that all the slides are there to use there is no need to sort through hundreds of glass slides to find the one you need. [VM16]

Reduced health issues (15% total, 5% OM, 21 VM)

> I found it very convenient and easy to use. I enjoyed using it as I had used the optical microscopes in other classes previously and with using it I experienced eyestrain and headaches. I did not experience this with the virtual microscope. [VF29]

Convenience (10% total, 19% OM, 0% VM)

> ...and above all convenient to use [OF2]

Examples (3% total, 5% OM, 0% VM)
Some students though the virtual microscopes provided more examples of pathology, despite having the same class slide set.

> …and increased examples of pathology [OM56]

Group work (3% total, 5% OM, 0% VM)
A few students felt that virtual microscopes made it easier to work in groups.

> That you could work in groups easier and point out things together [OF8]

Aspects students disliked about optical microscopes

Caused health issues (40%, total, 48% OM, 32% VM)

> They gave me constant headaches and sore eyes [OF8]
>
> In addition, using the microscope gave me motion sickness when other people were operating it. [VF26]

Difficult to use (35% total, 38% OM, 32% VM)

> Difficult to use, focus, find right slides, missing slides etc. [OF10]
>
> Can be a bit complicated to operate because of all the parameters that can be adjusted. [OM19]

Difficulties in group work (30% total, 33% OM, 26% VM)

> One criticism of the group working was that if one group was more vocal and asked the teacher more questions he would tend to spend a lot of time at that group. I felt this hindered my learning a fair bit as he usually ended up spending a long time with one specific group [OF15]
>
> Sometimes you want to look at something a bit longer or sketch something, but you don't want to have to make the group wait. [VM13]

Time consuming (15% total, 14% OM, 16% VM)

> I find the optical microscopes more of a hindrance than a help. They take a lot longer to set up than the virtual microscope does, you have to find the slide, make sure you have it on the viewer correctly [VM16]

Missing optical slides (8% total, 14% OM 0% VM)

> The time spent looking for slides that had not been put back into the correct box [OF1]
>
> Sometimes slides are missing - then we can't look at things. [OF40]

More experience required (5% total, 10% OM 0% VM)

> It takes experience to operate it efficiently. There is the tendency to always let one person drive if they are good at it and then when faced with wanting to use them alone, one finds it very difficult. [OF2]

Disliked everything (3% total, 0% OM 5% VM)

> The whole apparatus, but especially the binocular eyepieces. . [VM57]

Aspects students disliked about virtual microscopes

Clarity (38% total, 38% OM, 37% VM)

> [virtual] Images at higher magnifications are not as sharp and clear [OF2]
>
> Another problem that I've encountered is regarding the pixels. This has happened to me for a number of times, after I've zoomed in and out 1 slide for around 5 minutes, the slide clarity would then deteriorate, and all you can see when you want to zoom in (say x40) are random pixels [VF38]

Time management (13% total, 0% OM, 26% VM)

> Took too long to load up sometimes [VF35]
>
> Sometimes the images wouldn't load or sometimes the whole Image Scope freezes [VF42]

Restricted access (13% total, 5% OM, 21% VM)
Students identified access as a restriction that they disliked about the virtual microscopes.

> Would be better if you could access the slides from home. [VM26]
>
> Would've liked to be able to access it from the Murdoch website rather than just in 2 computer labs [VF50]

Inhibits group work (5% total, 10% OM, 0% VM)
Ten percent of the optical group thought there was less discussion when using the virtual microscopes.

> There was also less group discussion involved as each student has a individual program [OF17]

Unreliable software or network (5% total, 0% OM 11% VM)

> The program crashing [VM45]
>
> There were no real major negatives to the virtual microscopes, this was the first time we had used them and everyone in the class seemed to get along well with using them and found them useful. The only thing I found that was a bit of a negative was that one morning the computers wouldn't work, or the network so we lost a bit of time- but I guess that is the case with all technology [VM16]

Less engagement, motivation and enthusiasm (5% total, 10% OM, 0% VM)

> The problem is we works in pair. it takes so much time for the tutor, [the teacher] to go around and explain. [OF33]
>
> I was easily distracted and i found [the teacher] couldn't adequately answer everyone's questions as effectively as when using the optical microscopes [OF15]

Less authenticity (5% total, 5% OM and 5% VM)

> You feel more of a distance to what you are looking at when you can't "put hands" on it. [OM19]

Students were also asked to describe: *How did the activities with microscopes help your understanding of the course?*

A majority of students commented positively on how the activities linked theory with practice and encouraged group discussions. A small minority commented that the activities did not help their learning at all.

Linked theory with practice (78% total, 72% OM, 86% VM)

> As the microscope activities followed the lecture material, this allowed me to better visualise and better understand the theory covered in the lectures. For example, knowing what oedema looks like microscopically helps me to understand the pathology [OF1]
>
> it gave me a good insight in what i was looking at after seeing the theory [OM3]

Did not help learning (5% total, 4% OM, 5% VM)

> It didn't [OM4]
>
> It didn't I preferred using a text book pictures where i had the answers instead of guessing what i was looking at [VF51]

DISCUSSION AND CONCLUSIONS

Implementation of virtual microscopy

Implementation of virtual microscopy into a curriculum includes both technological and educational components. We found the technological components relatively straightforward, but with some associated educational implications and limitations. Digitising the slides was subcontracted to a third party (RCPA-QAP Pty Ltd). The only input required from us was selection of an appropriate example of the original glass slide (with all key features included and minimal production artefacts), plus checking the digitised version of the slide for quality and orientation. We used a wireless intranet delivery of digitised slides. We could have delivered the slides using a DVD or preloaded onto the PC laptops, and this may have overcome the occasional network access problems reported by some students. Although the students were randomly allocated to either the optical or virtual microscopes for their classes, none were excluded from using either type of microscope for self-study purposes.

Effect on group work

A key outcome of this study was that the delivery mode of the virtual microscopy slides has an important influence on group work. Students reported that the optical microscopes had the advantage of promoting group work, which they found useful. This relates not to optical *vs*. virtual microscopy *per se*, but more to the fact that the optical microscopes were set up as ten-header units around a square table, with 2-3 students along each edge of the square. This arrangement puts the students in a small group, of up to 10, all facing one another, and all looking at exactly the same image. We found that delivering virtual microscopy, with students working on computers distributed linearly along laboratory benches, made the natural group size much smaller, around 1-3. Many students felt this was a disadvantage of the virtual microscopy class, compounded by the tutor spending less time per group due to the greater number of groups with this arrangement. Although a small percentage of the optical microscope group also identified virtual microscopes as reducing group work as each student can use their own program, none of these students had used the virtual microscopes for their lab work, but may have used them for self-study. We propose to revise our use of VM by placing the students in groups of 6-10, around a square table, using four laptops per table. Group work will be encouraged by assigning each table specific tasks on which they must collaborate. The larger group size will allow the tutor can spend more time per group.

Ability to study off campus

A further interesting finding was that the OM students undertook some microscopy at home, whereas the VM class did not. This is because some students in the optical group had their own microscopes at

home. Our wireless network delivery was not available to students off campus. We propose to address this by distributing the digitised slides on DVDs with the other unit materials, so students may use the slides off campus. We have in the past found that students make good use of static, annotated histology and pathology images made available online through WebCT, so we expect that the virtual slides are also likely to be used for private study. This should address one of the limitations of optical microscopy in teaching, specifically the limited availability of optical microscopes for private study and revision.

Health issues

Health issues are well-documented in professional daily users of microscopes, with up to 80% of such users reporting headache, backache and other problems (Kofler, Kreczy and Gschwendtner, 2002; Thompson, Mason and Dukes, 2003). With the relatively short duration and infrequent microscope usage in our study, it was surprising to find such a high proportion of students reporting motion-sickness, headaches, eye strain and other problems when using microscopy (primarily optical microscopy). We minimise the chances of neck and back strain by educating students in the correct positioning of their body with respect to the optical microscope. The important feature is to ensure the seat height is low enough that the user can look through the binocular eyepieces with a near straight back and neck. Motion sickness was reported as a problem by some students in this study. Interestingly, although motion sickness is known to be a problem with virtual reality environments (Golding, 2006), we found that the optical microscopes caused *more* motion sickness than the virtual microscopes. A binocular optical microscope user has their entire visual field devoted to the slide, and hence is more immersed in the environment than a user looking at a digitised microscope slide on a laptop screen, increasing the risk of motion sickness. The other factor with OM promoting motion sickness and discomfort is the unpredictable movement of the image. This is because a ten-header microscope has one 'driver' with all other viewers being slaves to the driver's navigation around the slide, or changing of magnification. This lack of control of the image, and the unpredictable nature of its movement, predisposes to user discomfort in the multi-header setting. The smaller group size with the laptops, their lack of visual immersion, and the more predictable movements of the image reduce the motion-related discomfort of the user. These technical issues cannot be overlooked, given the frequency with which they were reported in this study, and the likely adverse educational impact of such experiences. In this study, the cause of the reported headaches associated with optical microscopy is not clear, but may be associated with muscular tension arising from the need to maintain constant careful positioning of neck, head and eyes with respect to the binocular eyepieces. Further factors that might contribute to eye strain or headache might be incorrect adjustment of the binocular eyepieces, such that one eye sees an image in a different focal plane from the other. Such health issues related to optical microscopy may well have an adverse effect on students' motivation and participation, and hence are important educational considerations.

Technical problems faced by students

Whilst multiheader microscopes promote group work and have huge educational advantages over single user microscopes, they are more technically demanding to set up. This is because, whilst there is only one 'driver,' each user has to adjust their left and right binocular eyepieces to focus clearly on a focal reference point (the illuminated pointer arrow) at the start of each session. Failure to do this properly results in the driver claiming everything is sharply in focus (both pointer arrow and histological image) but some users finding that the arrow, the image, or both are not in focus. Single user microscopes do not have such requirements, but then do not promote group work, so we do not favour them, despite their simpler technical set up. Students in this study noted technical difficulties with light microscopy, related to focus, setting up Köhler illumination, and adjusting eyepieces for optimal multiheader usage. They generally found VM technically more simple. Provision of DVDs to students will address many of the perceived technical problems associated with the use of virtual microscopes, as they will not be tied to campus resources.

Authenticity in microscopy

Given the increase in computer usage in university education, it was surprising that so few students objected to yet further computer 'simulations' in their practical classes. It might be expected that

students would be disappointed at not using 'real' microscopes and 'real' slides, whereas only a small number of students reported that they liked or preferred the 'authenticity' of the optical microscopes. What are the key educational objectives? Is it essential to have the students develop technical skills and understanding of light microscopy, or is it more important that they can explore the microscopic world without being hindered by the technical constraints required for optimal usage of research-grade light microscopes? We felt that chiropractic students, whilst requiring an understanding of the microscopic structure and disease processes of the body, are less likely to need technical skills in light microscopy in their careers. An important consideration when implementing virtual microscopy into a curriculum is to what extent technical microscopy skills might be required in the cohort. For example, veterinary students might reasonably be expected to make use of light microscopes in general veterinary practice (skin scrapings for parasites, fine needle aspirate cytology). Additionally, students in biological sciences might find skills in light microscopy to be a useful research tool. The increasing use of digital microscopy in the workplace, including remote reporting (telepathology) and external quality assurance schemes (Furness, 2007), should address some concerns regarding the authenticity and real world relevance of virtual microscopy. These needs must be considered and weighed against the educational barriers that some students find associated with the technical demands of optical microscopy.

Image quality and other technical issues

Some students commented on the reduced image quality of the virtual slides. Indeed, image quality is noticeably reduced in the digitisation process we employed, but we ensured that the resolution enabled most key features to be seen on the digitised slides. A few limitations of virtual microscopy noted by the students included the lack of ability to fine focus up and down when examining features in detail, and the inability to adjust the lighting (condensor and iris diaphragm) to see refractile structures such as mycobacteria within macrophages.

We were encouraged by this pilot study, and shall use these findings to try and improve our teaching of histology and pathology to students in the health sciences. Specifically, the study suggested that virtual microscopy is found to have fewer adverse health effects, and greater technical accessibility than optical microscopy. As noted above, however, a distinction needs to be made between at least three separate, but interrelated learning objectives.

1. Developing practical skills in technical operation of a light microscope
2. Learning the *process* of examining a slide to find relevant areas, and interpreting them
3. Learning microscopic structure and function (histology and histopathology).

Additionally, given the importance of group work and collaborative learning, we shall adapt our delivery of virtual microscopy to encourage larger group sizes (which might address a potential fourth objective – gaining skills in group work). A blended environment, with both optical and virtual microscopy available, should allow maximum flexibility that encompasses the differing needs of students from different vocational cohorts. We shall expand virtual microscopy flexibility by making the digital slides and software available for private study and home use (rather than being restricted to the University intranet).

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