Descriptive paper

Evaluation of usage of virtual microscopy for the study of histology in the medical, dental and veterinary undergraduate programs of a UK university

Margaret K. Gatumu[1,2], Frances M. MacMillan[1], Philip D. Langton[1], P. Max Headley[1], Judy R. Harris[1]

[1]School of Physiology and Pharmacology, Faculty of Medical and Veterinary Sciences, University of Bristol, Bristol BS8 1TD, United Kingdom

[2]Centre for Comparative and Clinical Anatomy, Faculty of Medical and Veterinary Sciences, University of Bristol, Bristol BS8 1TD, United Kingdom

Running title: Changing from light to virtual microscopy

Correspondence to: Dr. Margaret K. Gatumu, School of Physiology and Pharmacology, University of Bristol, Medical Sciences Building, University Walk, Bristol BS8 1TD, United Kingdom. E-mail: Margaret.gatumu@bristol.ac.uk

Telephone: +44 (0) 117 33 11579; Fax: +44 (0)117 33 12288

ABSTRACT

This paper describes the introduction of a virtual microscope (VM) that has allowed preclinical histology teaching to be fashioned to better suit the needs of approximately 900 undergraduate students per year studying medicine, dentistry or veterinary science at the University of Bristol, UK. Features of the VM implementation include: 1) the facility for students and teachers to make annotations on the digital slides; 2) in-house development of VM-based quizzes that are used for both formative and summative assessments; 3) archiving of teaching materials generated each year, enabling students to access their personalized learning resources throughout their programs; 4) retention of light microscopy capability alongside the VM. Student feedback on the VM is particularly positive about its ease of use, the value of the annotation tool, the quizzes and the accessibility of all components off-campus. Analysis of login data indicates considerable, although variable, use of the VM by students outside timetabled teaching. The median number of annual logins per student account for every course exceeded the number of timetabled histology classes for that course (1.6 – 3.5 times). The total number of annual student logins across all cohorts increased from approximately 9,000 in 2007-08 to 22,000 in 2010-11. The implementation of the VM has improved teaching and learning in practical classes within the histology laboratory and facilitated consolidation and revision of material outside the laboratory. Discussion is provided of some novel strategies that capitalize on the benefits of introducing a VM, as well as strategies adopted to overcome some potential challenges.

Key words: Histology, E-learning, Computer-aided instruction, Undergraduate medical education, Digital morphology, Assessment, Educational methodology, Medical laboratory science

INTRODUCTION

This report concerns a novel implementation of a digital ‘virtual’ microscope (VM) system and associated formative materials used since 2007 at the University of Bristol, UK.

In 2000, a group from the University of Iowa changed from teaching with the light microscope (LM) to a VM (Harris et al., 2001). Subsequently, more reports on the use of a VM in medical education have been published and many report that the VM has revolutionized the teaching and learning of histology (Dee, 2009). Most of the reports have been on graduate students studying medicine, dentistry or veterinary science in North American universities. They report that the VM trumps the LM because it enables the learning of histology to transcend the classroom (Blake et al., 2003; Goldberg and Dintzis, 2007; Husmann et al., 2009; Collier et al., 2012). They also note that the virtual (digital) slides are standardized, eliminating problems of variability between tissue sections from the same block of tissue (Blake et al., 2003; Goldberg and Dintzis, 2007; Braun and Kearns, 2008; Pratt, 2009; Kumar and Velan, 2010; Collier et al., 2012) and that the VM allows efficient use of teaching time as it enables more slides to be included in a single timetabled practical class (Cotter, 2001; Harris et al., 2001; Krippendorf and Lough, 2005; Pinder et al., 2008; Husmann et al., 2009; Weaker and Herbert, 2009; Kumar and Velan, 2010; Collier et al., 2012). Importantly, the VM also facilitates collaboration between students during a class (Blake et al., 2003; Kumar et al., 2004; Krippendorf and Lough, 2005; Pinder et al., 2008; Husmann et al., 2009; Weaker and Herbert, 2009; Kumar and Velan, 2010; Collier et al., 2012; Sander and Golas, 2013). Favorable student feedback on using the VM compared to the LM has been reported in many studies (Harris et al., 2001; Heidger et al., 2002; Blake et al., 2003; Kumar et al., 2004; Krippendorf and Lough, 2005; Sims et al., 2007) including by our group (MacMillan et al., 2009).

However, there are also drawbacks to using the VM, including the high set-up costs (Goldberg and Dintzis, 2007; Pinder et al., 2008) and concerns that learners lose, or fail to acquire, the skills required to set up and use LMs (Kumar et al., 2004; Scoville and Buskirk, 2007; Pratt, 2009; Collier et al., 2012). There is also the impression that learners may memorize images and not appreciate the normal variation between tissue samples (Cotter, 2001; Scoville and Buskirk, 2007; Pratt, 2009; Collier et al., 2012). Finally, as with any tool that depends on complex and robust systems, virtual microscopy puts considerable demands on the local information and communication technology infrastructure, the reliability of which must be considered in the adoption of a VM for teaching, learning and (especially) assessment.

This report describes and evaluates the adoption in academic year 2007-08 of digital microscopy for approximately 900 students per year undertaking mandatory histology components in the first and second years of five-year professional undergraduate programs of medicine, dentistry and veterinary science at the University of Bristol. This implementation shares many of the strengths that others report, but has overcome some of the weaknesses by retaining access to light microscopes (LMs). It also incorporates several novel features; in particular students can create personalized annotations on the digital images, either during or after the class, and review and edit them whenever they log into their VM account. Students are also able to test their level of understanding by working through formative online quizzes that provide both instant feedback and statistics that aid subsequent structured staff support.

This study was granted ethical approval by the Ethics Committee of the Faculty of Medical and Veterinary Sciences, University of Bristol.

DESCRIPTION

Infrastructure for the 'virtual microscope' (VM)

The teaching laboratory:

At each of the 119 stations in the histology laboratory, there is a binocular LM. In 2007, 68 student desk computers were placed on the benches between the LMs (Fig. 1). After six years of use these have been replaced by desk computers with 22 inch flat screen monitors. There is also a teacher podium with a computer linked to three projectors, and incorporating a SMART Sympodium DT770 interactive screen and pen display with SynchronEyes software, version 7, (SMART Technologies, Calgary, AB, Canada) that permits teachers to monitor all student computer screens.

[Fig. 1 near here (single column width)]

The software:

Digital SlideBox (DSB) software (SlidePath Ltd, Leica Biosystems, Dublin, Republic of Ireland) provides web access for exploring a digital slide in the same manner as the LM is used with conventional glass slides. It also houses other histology educational resources (described below). The histology material can therefore be accessed from any networked device, and dynamic links can be used to link directly to any feature at any magnification on any virtual slide from any location world-wide.

Digital SlideBox can manage the image file types produced by different scanners. The digital images include *NDPI* files produced by a Hamamatsu NanoZoomer Digital Pathology System scanner (Hamamatsu, 2013), *svs* files produced by Aperio scanners (Aperio, 2013), and *tiff* and *scn* files produced by a Leica SCN400 scanner (Leica, 2013).

From a user perspective, DSB provides both fixed magnifications (standard x4, x10, x20 and x40) and seamless progressive zoom in and out (range x0.06 to x40), enabling ready switching between overview and high power observation without altering either the field of view or plane of focus. A thumbnail image of the entire slide shows the location of the main screen image on the slide at all times. There is also drag, rotate, a measuring tool, and (for multifocal slides; see below) a choice of plane of focus. An important feature is the ability for all users to make personalized annotations (involving drawing symbols and freehand drawing as well as alphanumeric data) on each virtual slide; these commonly include the identity, name, description and function of a marked structure. This feature is used such that annotations made by teachers are visible to all users, whilst those made by students are visible only in that individual's personal VM online account.

DSB also permits other file types to be housed within the VM for ready use, e.g. practical handbooks (prepared in Microsoft Word®) or presentations delivered at the start of a practical class (in Microsoft PowerPoint®). Recent versions of DSB also permit external images (e.g. radiographs) in several formats to be incorporated and manipulated in the same way as scans of glass slides.

The hardware:

The server and networking requirements are demanding, given that we run classes of up to 130 students accessing the same material at the same time, teach around 900 students each year, and maintain individual student accounts for the duration of each student's undergraduate training (see below). The software manages this well, but it became necessary to upgrade the two servers, housed in the University's Information Technology building, to run Windows Server 2008 R2 at 64 bit with 2TB hard disk capacity. The network operating speed is up to 125 MB per second. On the other hand, because only the data relevant to that part of the image being viewed is downloaded, the specifications for the local computers, whether in the laboratory or at home, do not need to be high, apart from the need for adequate monitors and moderate speed internet access.

User 'accounts':

There is one administrator account that provides access and editing rights to all of the histology content on the website. All lead teachers can access this account enabling them to view, edit (e.g. make annotations), upload, copy and use image and multimedia content developed across the three undergraduate programs. From this account, teachers can determine what material is visible to the different student cohorts. We also create and use accounts that provide teachers with the same view of the website that is visible to a particular cohort of students; this is an important aspect of quality control, helping to avoid unintended effects on the student experience (e.g. inappropriate visibility of material for that stage of the course).

A lead teacher is supported in each laboratory-based class by one or more assistant teachers. They use separate accounts that access all of the 'live' histology content and associated resources in a given academic year, permitting them to prepare for classes readily and remotely, but without providing them with the global editing rights held by the lead teachers.

Students use their university personal log-in data to give them tailored access to the content on the VM that is relevant to the particular program they are undertaking.

Histology teaching materials

The slide/image collection:

Our glass slide collection involves boxes of approximately 400 slides for each of the 119 student work stations in the histology teaching laboratory, plus specialist materials held centrally. Altogether the collection amounts to nearly 50,000 glass slides.

In order to determine which glass slides to digitize, in 2006-07 the content of the histology practical handbooks was reviewed for the three professional programs. An initial selection of approximately 200 glass slides was made by the relevant specialist teachers. Many slides could be used in all three programs, but some were required for just one program (e.g. ground sections of teeth for the dental program and species-specific tissues, such as rumen or chicken lungs, for the veterinary program).

The selected glass slides were then scanned in one plane of focus at the maximum-supported magnification of x40. Although significantly more expensive to digitize, a few slides that warranted the investment (e.g. blood smears and silver impregnated Golgi stains of nervous tissue) were also scanned in several planes of focus, also at x40. DSB allows the user to change the levels of focus for such multifocal slides while the magnification is kept constant, as is possible with a LM. These files are however large (e.g. a blood film slide generated a 12.2 GB file), causing unacceptably slow loading until the servers were upgraded to the specification indicated above.

Since 2007 we have progressively expanded the number of digital images from our own glass slides and from collaborating research laboratories. We also gratefully acknowledge the acquisition of a large digital collection (primarily of pathological material) from the University of Iowa. The digital collection now comprises over 1500 images.

While most material is of normal tissue, which is the focus of teaching and assessment on the preclinical courses in Bristol, related histopathology material has been developed progressively. Occasional reference to histopathology material interests students, helps to reinforce the importance of understanding normal histology, and thereby aids vertical integration in these professional programs.

Digital image quality assessment:

A substantial load that had not been fully anticipated was the digital image quality assessment process. Not only was it necessary to select the best glass slide (of about 130 copies) for each tissue section, but it was also essential to assess the quality of the resultant digital scans for correct focus of all areas of the scan, critical illumination, absence of blemishes etc. Notably, while the LM user can readily adjust for a section that is not lying entirely flat on the glass, the VM user cannot; so a scan showing such irregularity needs to be rejected and a different glass slide selected for scanning. The overall load for this process was shared between technical staff (for the overall technical quality) and the academic staff who knew which aspects of the slide were critical for specific teaching purposes.

Folder structure for teaching materials:

The VM website has been structured into a hierarchical collection of folders (by academic year, program and topic) that hold the virtual slides and multimedia attachments that are used in the histology courses. These folders contain either ‘live’ content that is in use in the current academic year, or archived material that provides students for the rest of their program with access to those folders used in their own teaching. Such archiving permits evolution of the teaching material without confusing previous generations of students who wish to refer to the learning materials they used themselves.

Organization of histology practical classes

The student cohorts:

Within a given academic year, there are timetabled laboratory histology classes for approximately 500 medical, 170 dental and 240 veterinary students in the first and second years of their five year undergraduate programs. The majority are taking their first degree program, are aged 18-20, and have no practical experience of microscopy. In addition well over 1000 students in later years of their programs can access archived material from outside the laboratory (see above).

General structure of classes:

At the beginning of an academic year, students receive a printed histology handbook tailored to their course. The structure and learning objectives identified in these handbooks have been retained through the transition from the LM to the VM, although the content has evolved to suit the new style of teaching. All first year students begin their histology course with a session on how to use both LM and VM.

Each timetabled histology laboratory class is compulsory and lasts for 2-3 hours. The number of timetabled hours allotted to histology teaching per academic year varies between the programs: for first and second year courses respectively, it is 22 and 11 for medical, 18 and 17 for dental, and 32 and 47 for veterinary students. As a proportion of the total teaching load, these hours comprise, for first and second years respectively, 4.5% and 2% for medical, 4% and 2.5% for dental, and 5.5% and 9% for veterinary students. The higher allocation on the veterinary program reflects not only the greater range of materials covered across species, but also the relatively greater need for veterinarians in general practice in the UK to have practical microscopy expertise.

Lead teachers have flexibility over how to structure their classes. Each practical class involves a combination of a short lecture-demonstration by the lead teacher followed by exploration by the students of the relevant histology slides in the 'live' VM folders. The content covered mirrors the notes presented in the course handbooks. The balance of guidance *vs*. self-organized learning evolves as students gain histological experience.

Light vs virtual microscopy:

The collection of glass slides is still available at each workstation, so every student is able to access both the LM and the VM during all histology practical classes. There are also three to four 'hybrid' practical classes per program in which students are *required* to use both tools. For example LMs are used in the veterinary practical class for the study of spermatozoan motility, and in other practicals where oil immersion is required for higher magnification of specimens than is available in the digital slides. This is also in line with the learning objective for Bristol students to achieve competence in using an LM. Some students will occasionally use the LMs voluntarily, whether to practice their LM skills, check multiple planes of focus, or perhaps investigate a glass slide that has not been digitized.

Retention of light microscopy has enabled feedback data to be collected from students, who can compare the two approaches. A voluntary, anonymous, 'free text' survey of second year medical students carried out in 2012-13, and illustrated in Fig. 2, showed that, although all 136 students who completed the survey (55% of the cohort) prefer using the VM to the LM, some do worry that they lack LM skills.

[Fig. 2 near here: requested ~1.5 column width]

Slide annotations:

Material in the handbooks is supplemented by annotations applied by the lead teacher to the virtual slides. Most students also make their own personalized annotations on the virtual slides. Increasingly, we find that students create initial personalized annotations as the lead teacher goes through the introductory demonstration session in a process akin to taking notes in a lecture; these annotations can then be expanded during the subsequent period of self-directed examination of the ‘live’ VM material.

Students greatly value the annotation feature; in the survey summarized in Fig. 2 it was rated by almost half of the responding students as the best aspect of the VM. Furthermore, the fact that some slides (intentionally) lack annotations applied by the lead teacher was cited by 24% (19) students in the survey as an inadequacy of their teaching. However, such slides are deliberately left without annotations, so requiring students to explore and label structures on their own. This provides them with an important incentive to learn to make use of, and integrate, diverse resources such as handbooks, textbooks and the internet. It is also notable that a single temporary failure of the student annotation feature (rectified by the server and software upgrade, see above) generated marked critical feedback from the affected cohort of students, also shown in Fig. 2.

Histology assistant teachers:

A key component of the success of the laboratory classes is the well prepared assistant teacher. In collaboration with the lead teacher, they roam the laboratory and guide the students in reviewing the structures on their computer screens. They also help students revisit questions that they have answered incorrectly in the formative quizzes (see below).

Formative feedback for students

A formative histology quiz usually forms part of each histology laboratory practical class and can also be accessed after the class. Some quizzes take place at the end of the class and relate to that day's material; others are held at the start of the following class and relate to material covered in the previous class. Both strategies are employed (although not usually in the same practical class) as the former enables rapid correction of any misconceptions, whilst the latter encourages students to reflect on and consolidate their longer-term learning.

Most quizzes are built and run using the questionnaire feature within the DSB software. This allows students to navigate virtual slides in real time, to submit their answers online (see Fig. 3A), and then to receive instant feedback on the correct answers. They also receive numerical information on their own performance as well as a comparison with the rest of their student cohort.

[Fig 3 near here: requested double column width]

The DSB questionnaire feature saves all the student performance data, which can then be harnessed and presented in a spreadsheet such as that shown in Fig. 3B. This provides an important educational resource that is made available on the VM to both students and teachers. It can be used to set the agenda of an end of year revision session during which the attention of both teachers and students can be focused on poorly scoring questions, maximizing the learning opportunities provided by the presence of staff.

Other quizzes are generated using static images copied from the VM material and incorporated into files using third party software, normally either Microsoft PowerPoint or TurningPoint 2008® (Turning Technologies, Youngstown, Ohio). For example, interactive quizzes consisting of multiple choice (best answer from five) questions have been constructed using the animation features of PowerPoint, and are made available to second year medical students both during and after timetabled histology classes. This question format matches that of the summative histology examination questions for this cohort of students. Quizzes composed within TurningPoint are always held in a plenary session in which all students use voting handsets, which has the advantage of promoting class discussion. The multimedia files are all uploaded onto the VM to facilitate subsequent access by students both on- and off-campus, enabling provision of immediate and longer-term feedback that mirrors that described above for the DSB-generated quizzes.

All types of formative quizzes are well received by students, as shown in student surveys. As well as the data in Fig. 2, e-voting surveys of other student cohorts showed that quizzes were rated as excellent/good learning tools by 79 % and 97 % respectively of second year medical and veterinary students.

The VM has also facilitated the introduction of a mock examination that is run for most first year student cohorts. Such sessions (which were quite impractical when using the LM) not only provide technical practice of the relevant question formats prior to summative assessments, but permit teachers to provide an immediate review of the material assessed and/or any other material covered in the year as requested by students.

Summative assessments

The VM is also used in a variety of formats for summative assessments. However, in this implementation all summative examinations require students to submit written answers, which are then optically marked by a scanner or, occasionally, hand marked. These approaches avoid online security and reliability concerns. The optically marked scripts provide detailed analysis that enables the quality of questions to be assessed by comparison of individual question performance to overall cohort performance, providing important quality assurance.

As a contingency in case of system (i.e. technology infrastructure) fault at the time of a summative examination that utilizes online ‘live’ VM images, a backup examination composed of static (printed) images is available for each cohort of students.

Use of the 'virtual laboratory' by students and staff

Student use:

During classes the majority of students work in pairs in front of a desk computer (Fig. 1). Most student pairs appear to enjoy, and benefit from, working together to review the virtual slides. Some prefer to work alone, and some bring their own laptops and use the wireless internet connection that is available.

Anecdotal reports indicate that many students also work together outside classes, but this cannot be quantified. What can be analyzed is the total number of logins (i.e. the number of times, of any duration, that each student user signs into the VM website to obtain access to the resources) undertaken over the course of an academic year. Cooperative working means that such figures will be an underestimate of real student use, but they provide a reliable minimum value of student access.

However, it is not simple to extract such data from DSB. The first step was to check, and if necessary correct, the lists of account holders; for instance, some students open a second account when they cannot remember their username or password for an existing account. Non-students (teachers, guests and system administrators) also needed to be excluded from the analysis. The extraction of login data per user can only be undertaken by the system administrators at Slidepath, and is labor-intensive. Slidepath's cooperation is appreciated in generating the data for the first four years of use of the VM (2007-2011).

The number of timetabled histology practical classes for each cohort of students remained largely unchanged (averaging 9 per year) over the four academic years analyzed. In contrast, the total number of logins made by students (across all cohorts) increased from around 9,000 in 2007-08 to 22,000 in 2010-11. This is reflected in the median number of VM logins per student account per year, which over that period increased from 11 to 21.

Fig. 4A provides more detail. In 2010-11, over 30% of student VM accounts were accessed on at least 30 occasions during the academic year (almost half of these on over 50 occasions), whilst that frequency of access was recorded for only 5% of student VM accounts in 2007-08. At the other end of the scale, the percentage of student accounts accessed on 10 occasions or less during an academic year approximately halved over that time. These data indicate a marked increase over the four years in the proportion of students who, over the course of the academic year, log into the VM several times more often than the number of timetabled classes on their course.

[Fig. 4 near here: requested width of two columns]

Fig. 4B provides login data for individual student cohorts for 2010-11. It shows clearly that the median number of logins per student account (red bars) exceeded the number of timetabled laboratory classes (white bars) for every course. The ratios between these, for first and second year cohorts respectively, were 3.0 and 1.6 for medical, 1.6 and 3.5 for dental, and 2.5 and 2.6 for veterinary students. The distribution of logins for each student cohort was strongly skewed, as shown by the highest number of logins recorded for any single student account (black bars).

Staff use:

Teachers also report accessing the VM outside the teaching laboratory - from their offices, in lecture halls, in the anatomy dissection room, from home and at conferences.

DISCUSSION

This report shows how the teaching and learning of histology has been enhanced and expanded by incorporating the VM into histology teaching in the first two years of the undergraduate professional programs of medicine, dentistry and veterinary science, whilst maintaining the core histological content and teaching strategy developed over many years using the LM. This approach offers every student and teacher access to the best examples of the different specimens in the glass slide collection, plus variations in histological features, different histological stains, aspects of histopathology, and formative quizzes. By these means, students gain insights into the relevance of core histology, structure-function relationships, and the nature of the histopathology that they will encounter later in their careers. The images used by students include generic staff annotations and they add their own personalized annotations and notes. Being web-based, all of these resources can be accessed not only during laboratory classes but also globally at any time. They also remain accessible throughout a student's undergraduate program.

Aspects of implementation:

Despite the many advantages, there are technical and manpower challenges encountered with introducing and using a VM. Technical problems with downloading and accessing virtual slides, particularly with multiple simultaneous users, have been reported previously (Husmann et al., 2009; Weaker and Herbert, 2009; Bloodgood, 2012; Collier et al., 2012). In our system, this occurred but it was resolved by increasing the processing power and memory of the servers.

Creating and annotating a high quality collection of digital images is labor-intensive at the outset, but it enables staff expertise in histology – a resource that is becoming more scarce as expert teachers in the field retire and are not always replaced - to be 'archived' for the benefit of future teachers and students. Our experience indicates that the initial resistance to changes in teaching methods by some staff is short-lived once the many benefits of the VM become clear.

Concerns over the loss of opportunities for students to develop light microscopy skills can be minimized by retaining access to LMs, even if only for occasional use. The teaching laboratory at Bristol allows the teacher or student to revert to the LM and glass slides as the need arises, e.g. when higher magnification using oil immersion is required, or when depth of focus is particularly helpful. By maintaining both options, future health professionals can thereby also obtain useful skills in both electronic and traditional histology tools. Indeed, the majority of clinicians surveyed by Pratt (2009) felt that traditional microscopy skills were key to a successful clinical career. However, there are appreciable space constraints and maintenance costs associated with keeping LMs and glass slide collections; sole use of the VM would overcome many of these constraints (Blake et al., 2003; Krippendorf and Lough, 2005; Deniz and Cakir, 2006; Pinder et al., 2008). Only time will tell how long it will be possible to maintain a large laboratory equipped for these two parallel streams of teaching and learning.

The teacher perspective:

In the Bristol implementation of the VM, the introductory talk by the lead teacher at the beginning of each practical class is followed by students being left to plan how to use the remainder of the timetabled session. This format has been reported in other institutions (Heidger et al., 2002; Blake et al., 2003). In our case the flexibility allowed to students is greater with the more experienced second year students. There is better use of the teacher who can offer more effective and individualized help to students. In this way, and as in a previous study (Goldberg and Dintzis, 2007), the conversations between teachers and students in the histology laboratory are now focused on histology content rather than on the tool, as was too often the case when only the LM was used. This and the access outside the classroom encourages students to become independent learners who take increased responsibility for their own learning (Moore, 1973), choosing exactly when, where and how it is most appropriate for them to study. This permits a shift in the role of the teacher from being the key source of information to being a facilitator of discussion and learning, which in turn empowers students with lifelong learning skills (Rogers, 2000).

It is during the student-centered periods of a timetabled class that discussions with students can arise (including with those who struggle to identify particular structures that have not been annotated by the teacher, as noted in data from the survey illustrated in Fig. 2). If relevant, the teacher can then illustrate the topic to the entire class using the projector screens, thereby encouraging students to make correct annotations and pre-empting cohort-wide misunderstanding.

In terms of formative and summative assessment, it is far easier with the VM than LM to assess students' knowledge and understanding of histology. This may be with virtual slides on the VM or with static images derived from it. A significant advantage is the ability to provide instant feedback, known to be a powerful influence on learning (Hattie and Timperley, 2007); therefore online submission of answers to formative quizzes and provision of instant feedback is now routine practice across all our courses. Regarding summative assessments, risk-avoidance reasons for not adopting online submission of student answers have been highlighted, but many assessments still test students' ability to interrogate virtual slides.

While it has never been possible to assess the total hours spent on histology by students, the independence the VM affords has resulted in some students voluntarily spending less time in laboratory classes. Improvements in efficiency of use of timetabled classes can help to counter the time constraints increasingly faced by basic science courses (including histology) on professional programs. Declines in timetabled class time have been reported in some North American universities (Drake et al., 2009) and there is also a tendency to increased allocation of teaching time to the clinical components of these programs (Fernandes, 2004; GMC, 2009). The VM thus reduces the potential for this to impact adversely on the learning of histology.

Student engagement and benefits:

Most students work in pairs during timetabled practical classes, and many report that they also work cooperatively outside classes. While taking into account the concerns expressed about a 'watching' student who may not gain as much as the one who has the controls (Collier et al., 2012), most students engage fully and appear to profit from working cooperatively. As in the recent report from (Bloodgood and Ogilvie, 2006), students also share the learning responsibilities; for example while one student looks up content in a textbook, the other may be searching online resources.

The students are also supported by teachers who move around the laboratory to answer questions and proactively challenge students' understanding. Such active learning (Chi, 1996; Silverthorn, 2006) involves encouraging students to seek answers themselves, whether by group discussion or from resources such as their handbooks, an unopened textbook, or online.

Active learning is more often reported in small group teaching (tutorials) and some institutions are able to offer timetabled small group tutorials using the VM (Dee, 2009; Shaw and Friedman, 2012). In both these reports, students undertake group work and then give presentations to their peers. High student-to-teacher ratios at Bristol and in many other institutions (Stephen et al., 2008) are a reality and therefore large group teaching of histology has necessarily been retained with the transition from the LM to the VM. A recent report on active learning that incorporates students' presentations using the VM, but in a large group setting (Bloodgood, 2012), is therefore interesting. In implementation described here, the structure of the classes combines limited didactic teaching with teacher-directed and supported self-learning over which students take more responsibility as their histological insight develops.

The availability of archived material from previous years of each student's program provides continuity between the histology teaching in the first two years and also contributes to related learning by students in later years of their professional programs.

They are able, for example, to refresh their understanding of normal tissue structure when interpreting histopathological material and structure-function relationships in the clinical environment, because they can access the material (including their personalized annotations) they used in previous years. Overall, using the VM enables far more interaction with the histology and histopathology content in the program than would realistically be possible with the LMs.

The present report provides a strong indication that the VM is used outside the laboratory and supports the anecdotal descriptions of such use in various reports (Blake et al., 2003; Goldberg and Dintzis, 2007; Husmann et al., 2009; Collier et al., 2012). The data presented on the number of logins by students is akin to a log of the number of visits a student might wish to (but undoubtedly could not) make to a traditional histology teaching laboratory.

The login data presented here need to be interpreted in the context of students sharing computers on- and (probably) off-campus. Some registered students had very few recorded logins but others generated very high logins (in excess of 50 per academic year). It is therefore likely that in some cases there is a dominant account used by a pair of students. These results indicate how flexibly the VM can be utilized by learners to suit their individual needs, as is the case with other web-based resources (Sheard et al., 2003; Bacro et al., 2010).

One potential distorting factor in the login data is that users may have logged in and out multiple times during timetabled class time. However, monitoring student screens on the teacher's podium using the SynchronEyes software indicates that students log in at the beginning of the class, view the content with the lead teacher and then on their own, and log out at the end of the class. There is no need for students to log out of the VM when viewing other online resources that are sometimes used in the class as they can, and readily do, open multiple windows and tabs.

The appreciable differences between student cohorts in their median login data may arise from a number of factors. For example, the logins by second year students are likely to have included revision of the archived material they used in their first year. The virtual slides also differ in the amount of visually complex material presented within them; some tissues (such as horse hoof in the second year veterinary program and teeth in the second year dental program) are complex three dimensional structures that are difficult to visualize from two dimensional tissue sections, so might be expected to require more revisiting of the slides. Regrettably, however, the login data do not permit an analysis of the individual slides accessed at each login. Moreover the system data mining did not provide the date of login, therefore precluding an analysis of the balance between consolidation shortly after a class and revision at a later date.

There are several possible explanations for the increase in the number of student logins over the years since introduction of the VM. First, the bank of online resources available to students (virtual slides, annotations and quizzes) has increased steadily, providing successive generations of students with greater incentives to make repeated formative use of the resources. Second, the relative ease of preparing and (particularly) marking assessments, compared to when using the LM, has meant that there are now more formative and summative assessments in histology, encouraging students to log in to revise. Also, much more comprehensive feedback on performance in assessments is provided to both students and staff than in the LM days. The VM permits students to readily revisit the virtual slides after assessments to review their understanding. The impact of the VM on the performance of students in summative histology assessments over the years and across programs is currently being evaluated.

Conclusion:

Overall, the VM has been found to facilitate teaching, learning and assessing histology for large numbers of students across multiple programs, with its benefits greatly outweighing its challenges. Student surveys (e.g. Fig 2), completion of quizzes, login data (e.g. Fig. 4) and anecdotal evidence all indicate that students access the VM voluntarily and repeatedly outside the teaching laboratory, including outside term-time, demonstrating how valuable they find it for their learning.

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NOTES ON CONTRIBUTORS

MARGARET GATUMU, B.D.S., Ph.D., is a teaching fellow jointly between the Centre for Comparative and Clinical Anatomy, and the School of Physiology and Pharmacology, Faculty of Medical and Veterinary Sciences, University of Bristol, Bristol, UK. She teaches histology, anatomy and physiology to medical, dental and veterinary students.

FRANCES M. MACMILLAN, B.Sc., D.Phil., is a senior teaching fellow in the School of Physiology and Pharmacology, University of Bristol, Bristol, UK. She teaches histology and physiology to medical, veterinary and BSc students and her research interests are the development and evaluation of novel teaching and assessment methods.

PHILIP D. LANGTON, B.Sc., Ph.D., is a senior lecturer in the School of Physiology and Pharmacology and Director of e-Learning in the Faculty of Medical and Veterinary Sciences, University of Bristol, Bristol, UK. He teaches physiology and histology to veterinary and BSc students. His research interest is the development of teaching strategies.

P. MAX HEADLEY, B.V.Sc., B.Sc., Ph.D., is a professor of physiology in the School of Physiology and Pharmacology, University of Bristol, UK. He teaches physiology and histology to veterinary and BSc students and his research interest is the physiology of spinal nociception.

JUDY R. HARRIS, B.Sc., Ph.D., is a professor of physiology in the School of Physiology and Pharmacology and Director of the AIMS Centre for Excellence in Teaching and Learning; University of Bristol, Bristol, UK. She teaches physiology and histology to medical, dental and BSc students. Research interests include developing and evaluating teaching strategies.

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FIGURES

Figure 1. Use of the virtual microscope (VM) and traditional light microscopes in the histology laboratory. 'Live' VM images selected by pairs of students are visible on their desktop computer screens. The teaching podium and associated audio-visual aids can be seen towards the top of the photograph. The 'live' image from the lead teacher's screen is visible on the two (of three) large, drop-down projector screens, at least one of which can be seen from any position within the laboratory.

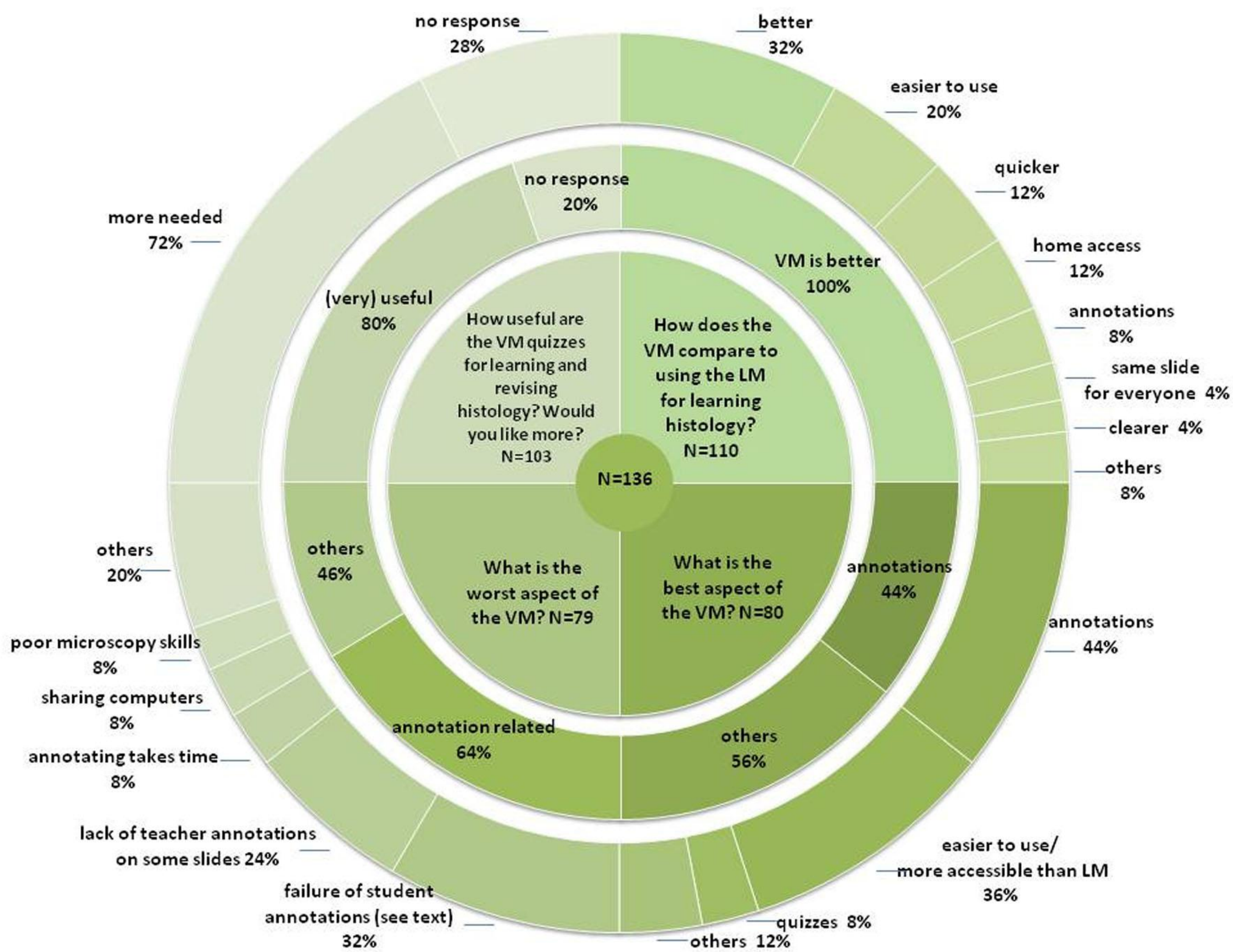

Figure 2. Students' feedback on the use of the virtual microscope (VM). Medical students in their second year were asked to provide anonymous feedback using free form answers to the questions shown. They were free to answer all/some/none of the questions. 136 students (55% of the cohort) participated in the survey. The number of students who answered each question is shown after the question. The free form answers given by the students are summarized in the figure with the inner doughnut chart displaying the general themes and the outer doughnut chart, the specific points made. The percentages shown are the proportion of students who gave a particular answer out of the total who answered a specific question.

A

B

	A	B	C	D	E	F	G	H	I
1	**QUIZ:**	**Endocrine system**							
2		Hyperlink to quiz							
3									
4	Questions 1 - 3	Thyroid and parathyroid, dog (HE)							
5	Questions 4 - 6	Adrenal, horse (BT)							
6	Questions 7 - 8	Pancreas, cat (Gomori's Chrome Alum H/Phloxine)							
7	Questions 9 - 12	Pituitary, ox (BT)							
8	Right hand column of each pair shows the **percentage** of student pairs who gave that answer								
9	Yellow cells	indicate the correct answer							
10	Blue cells	indicate all those answers indicated as correct in more than 10% responses							
11	Slide	1		1		1		2	
12	Tissue	Thyroid and parathyroid, dog (HE)						Adrenal, hors	
13	Question:	1		2		3		4	
14		Which encircled area corresponds to tissue responsible for the regulation of blood calcium?		Which arrow item indicates a cell type responsible for iodide trapping?		Which arrow item represents a store of iodinated thyroglobulin?		Which of the areas indicated contains cells under the control of ACTH?	
15	Number	A	3%	A		A		A and B	14%
16	of responses	B	45%	B		B		B	48%
17	from student pairs	C	52%	C		C		B and C	29%
18	72			D	1%	D	1%	D	10%
19				E	1%	E			
20				F	4%	F			
21				G	3%	G	4%		
22				H	89%	H	4%		
23						I	90%		
24									
25									

Figure 3. Formative assessments using Digital Slide Box (DSB) software. A.

Screen capture showing part of a quiz (on endocrine system) based on virtual slides. A student would read the questions in the left panel and then navigate the slide to address the question. This involves changing location and magnification; note that a particular advantage of the VM over the LM is that cursors in the thumbnail always indicate the location of the field of view on the section. The student would then choose an annotated structure (annotation titles only become visible when the cursor is hovered over the selected structure, so only annotation title ‘B’ is shown in this screen capture) and submit their answer in the panel on the left. **B.** Screen capture of part of a spreadsheet showing a typical analysis of performance for a cohort of students (here, second year veterinary students). Slide 1 and Questions 1-2 in the quiz are shown in **A.** Dynamic links (blue, underlined text) in the spreadsheet allow quick access to the relevant slide and quiz held within the VM. Questions 1-3 were well performed while Question 4 illustrates poor understanding by students, permitting targeted staff feedback on the topic.

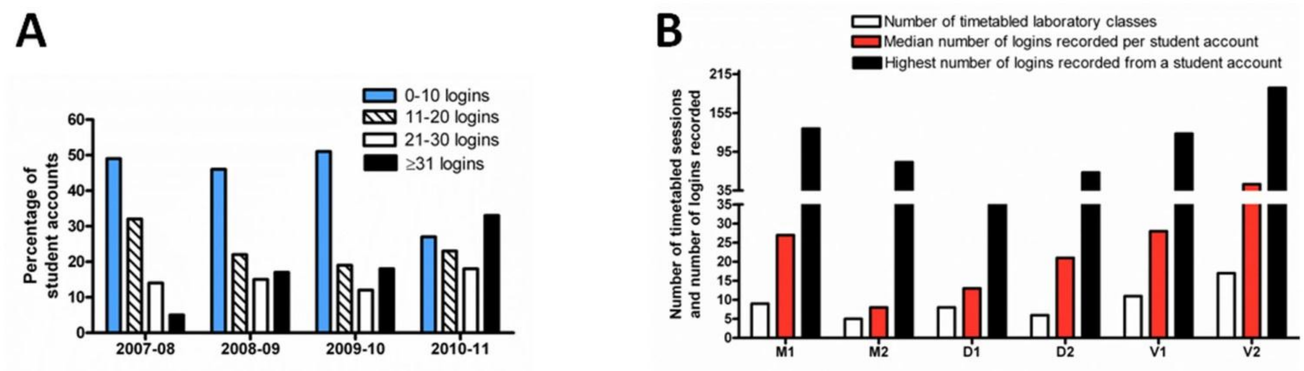

Figure 4. Student use of the virtual microscope (VM). A. Increase in the frequency of logins (defined in text) per year for all students on the three professional programs across the four academic years after introduction of the VM in academic year 2007-08. For each academic year, the groups of bars show the percentage of student accounts from which the given number of logins shown in the key were recorded. **B.** Student cohort login data for the academic year 2010-11. The number of timetabled histology practical classes (white bars) is shown for first and second year medical (M1 and M2), dental (D1 and D2), and veterinary (V1 and V2) students. Red bars show the median number of logins recorded over the academic year for each cohort (and therefore include logins both on- and off-campus). Black bars show the highest number of logins by a single student's account.