Technical Note

Turning Microscopy in the Medical Curriculum Digital: Experiences from The Faculty of Health and Medical Sciences at University of Copenhagen

Ben Vainer[1,2], Niels Werner Mortensen[3], Steen Seier Poulsen[4], Allan Have Sørensen[3], Jørgen Olsen[5], Hans Henrik Saxild[6], Flemming Fryd Johansen[1]

[1]Department of Biomedical Sciences, Molecular Pathology Section, University of Copenhagen, [2]Department of Pathology, Copenhagen University Hospital, Rigshospitalet, [6]The Dean's Office, Faculty of Health and Medical Sciences, University of Copenhagen, [4]Department of Biomedical Sciences, Endocrinology Research Section, University of Copenhagen, [3]IT Services, Faculty of Health and Medical Sciences, [5]Department of Cellular and Molecular Medicine, Section VIII, University of Copenhagen, Copenhagen, Denmark

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Abstract

Familiarity with the structure and composition of normal tissue and an understanding of the changes that occur during disease is pivotal to the study of the human body. For decades, microscope slides have been central to teaching pathology in medical courses and related subjects at the University of Copenhagen. Students had to learn how to use a microscope and envisage three-dimensional processes that occur in the body from two-dimensional glass slides. Here, we describe how a PathXL virtual microscopy system for teaching pathology and histology at the Faculty has recently been implemented, from an administrative, an economic, and a teaching perspective. This fully automatic digital microscopy system has been received positively by both teachers and students, and a decision was made to convert all courses involving microscopy to the virtual microscopy format. As a result, conventional analog microscopy will be phased out from the fall of 2016.

Keywords: Digital microscopy, education, histology, pathology, virtual microscopy

Introduction

The University of Copenhagen (UCPH)'s histology and general pathology degree curriculum

A familiarity with the structure and composition of normal tissues and an understanding of the changes that occur during disease is pivotal to the study of the human body. For decades, microscope slides have played an important part in the curricula for medicine, odontology, and related subjects at the UCPH. Students had to learn how to use a microscope and envisage three-dimensional processes that occur in the body from two-dimensional glass slides.[1-4]

To date, the histology and general pathology bachelor courses have been characterized by classrooms full of dual-view microscopes, each with a secondary ocular for the teacher, together with boxes of glass slides. Course administrators had the laborious task of keeping the collections up-to-date. At a college where 120 students are often taught simultaneously, generating the required sections for each student from relevant tissue samples can be challenging, and providing specimens from small biopsies illustrating rare conditions is almost impossible. In addition to this, cleaning and servicing the microscopes is expensive.

As a practical consideration, teachers often had to provide one-to-one tuition with students at their microscope with the teacher using the secondary ocular. This decreased the time spent instructing the rest of the class and reduced overall teaching efficiency significantly.[2-8] In addition, these one-to-one sessions demonstrated that many students were unable to obtain an image on their microscope and also found it difficult to locate relevant areas on their slides.

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Address for correspondence: Prof. Ben Vainer, Department of Pathology, Rigshospitalet, University of Copenhagen, Frederik V's Vej 11, 2100 Copenhagen, Denmark. E-mail: ben.vainer@regionh.dk

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Teaching Considerations

At UCPH, coursework is presented either as lectures or as lessons with classrooms of up to 24 students. For general pathology and histology, the classroom lessons focus on studying specimens using microscopy. Because lecture notes and other resources were previously not available online, the students had to attend all the lectures and lessons or alternatively rely on textbooks. Therefore, the students were restricted in their approach to learn the curriculum.

We considered this arrangement as a very static approach that did not take modern theories on education into account. The idea of converting this rather rigid educational process into one which was more flexible, providing each student with more freedom to interact individually with the curriculum, arose with the introduction of whole slide imaging scanners. In addition, recent software- and internet-based methods had demonstrated the suitability of live streaming movie clips for teaching and how e-learning initiatives could be used to show short movie clips while lecturers provided a commentary on specific subjects.

We wanted to develop a dynamic and easy-to-use platform that was focused on optimizing education in histology and pathology for the benefit of future clinicians. This solution had to be user-friendly for both students and their educators and needed to be available 24 h-a-day to all users. Critically, the platform had to ensure that teaching, curriculum, and examination objectives were all aligned. This manuscript explains our approach and the considerations that led to the implementation of the digital microscopy learning platform called VIRMIK (an acronym for virtuel mikroskopi, which is "virtual microscopy" in Danish) for all bachelor's degree studies at UCPH's Faculty of Health and Medical Sciences.

The Learning Environment

For the last decade, the general pathology course has included three distinct elements, each with different learning goals. These elements are lectures, microscopy lessons with one teacher per 24 students wherein selected microscopy specimens are scrutinized, and case studies with one teacher per 24 students wherein theory from the lectures are combined with information from textbooks, microscopy, and clinical information [Table 1].

Microscopy of tissue specimens is a central element of both the case studies and the microscopy lessons. However, conventional microscopy with boxes of glass slides is a cumbersome procedure, and even when preparing for exams, the students are only permitted to study the specimens in microscopy classrooms or study halls, which are not always open. We wanted to develop a learning environment that was tailored to student needs and independent of study hall opening hours and teachers or assistants supplying slides. In addition, we wanted to use a framework based on platforms familiar to twenty-first-century students, while remembering

Table 1: Learning elements, their objectives and topics

Learning element	Objectives	Topics
Lectures	General overview	Cell damage and adaptation
	Detail-oriented theory	Cell death (apoptosis and necrosis)
	Research-based	Amyloidosis
		Ageing
		Acute inflammation
		Chronic inflammation
		Granulomatous inflammation
		Cellular matrix in inflammation and repair
		Coagulation disturbances
		Atherosclerosis
		Infarction, oedema and aneurisms
		Circulatory disturbances in the brain
		Nomenclature of neoplasms
		Criteria for malignancy
		Invasion, metastasis and cellular matrix in neoplasia
		Cell biology of neoplasia
Microscopy lessons	Microscopy of specific cellular changes and tissue changes	Cytopathology (adaptation, accumulation, cell death)
	Linking theory to observable changes in the microscope	Inflammation (acute inflammation, chronic inflammation, healing)
		Circulatory disturbances (arteriosclerosis, infarction, homeostasis, thrombosis, cardiac insufficiency)
Case studies	Patient cases	Apoptosis and necrosis
	Microscopy	Acute inflammation
	Theory	Chronic inflammation (hepatitis)
	Linking theory and laboratory work with patient symptoms	Atherosclerosis and acute myocardial infarction
		Breast cancer
		Colorectal cancer

that many medical doctors use microscopes as part of their daily routine.[4,9-14]

Aligning the Study Elements

Teaching resources are increasingly digital and the computer has become central to learning. Several specific e-learning platforms have been developed that support conventional face-to-face teaching methods involving teachers and students. One of the challenges for including e-learning platforms in a curriculum is to ensure that the teaching, the curriculum, and the concluding examination can all be aligned. Therefore, it was critical that the IT platform selected could be applied to all these study elements.

Constructing a website for the digital microscopy of human tissue specimens was considered the most important activity. Once the website was established, microscopy could be used to teach all elements of the courses. It could be used in the microscopy classes, during the lectures and case studies, and it could also be used for examinations. The examinations would be able to pose real microscopy questions, even in test rooms not equipped with conventional microscopes. This would make the questions more realistic than questions using still photos. The goal was to create a system that was compatible with a variety of modalities, including two- and three-dimensional macroscopic images of organs, ultrasound, X-ray, computed tomography, and magnetic resonance imaging images. We would then have a system capable of presenting all imaging modalities relevant for each particular case.[15]

Proper alignment of the study elements would allow microscopy to be seamlessly embedded in all aspects of the course, improving the students' microscopy knowledge and performance. We believe this also prepares the students for subsequent clinical courses leading to master's degrees and their postgraduate professional work.[4,5,15-18]

Pilot Project

Mirax scanner (3DHistech) with still photos used during written examinations

A pilot project using whole-slide scans made by a Mirax Midi Scanner (3DHistech Ltd., Budapest, Hungary) was initiated in 2006. Slides were chosen from the existing tissue collection used in the pathology courses and scanned at ×20 magnification. The scanned slides were stored on local computer hard drives and individual files copied to all the teaching computers. The students could retain a copy of the scanned slides on their personal flash drives.

Because the images were stored locally, it was not possible to save annotations (i.e. markings of interest) on the scanned files, although the slides could be annotated individually on each teacher's workstation.

Virtual microscopy could not be used in the examination rooms because the slides could not be stored on the central examination server. Therefore, still photos of the digital slides were used in the examination questions. This was the first step toward introducing images of histopathological changes into a written examination setting at UCPH. The next step was to upload software compatible with the Mirax scanner file format (Mirax Viewer – later called Pannoramic Viewer; 3DHistech Ltd.) onto the examination room server, allowing the relevant digital microscopy slide files to be uploaded centrally and the students to perform virtual microscopy during the examination. It remained difficult to include annotations, limiting the scope of the examination questions that could be asked.

A Windows 2008 Server virtualized using VMware, and MIRAX server software supporting the .mrxs digital slide format were installed. A VPN connection was used to upload digital slides to the server, making uploading very slow. The Mirax Viewer had to be installed manually on each workstation to access the digital slides stored on the server.

A Permanent Solution: The University of Copenhagen Virmik Platform

Construction of the VIRMIK platform

After conducting the pilot study, which was received positively by both students and teachers, we developed a system that could be applied to all courses that included microscopy. This required the purchase of digital microscopy viewing software for the server, which could be used as part of a general system for distributing image files across the university campus network. This system was named VIRMIK, an acronym of virtuel mikroskopi, which is "virtual microscopy" in Danish.

The system allows the inclusion of explanatory text linked to each digital slide, supplementing the theory presented in textbooks and explaining each slide in detail, including any features due to disease. Permanent annotations can also be added to show both normal structures and pathogenic abnormalities, increasing the clarity of each specimen.[2,7,19-21]

Specifications and requirements

The following basic design goals were specified as minimum requirements for the system:

- Optimized for classroom teaching
- Capable of supporting individual student learning and self-testing
- Compatible with completely digital examinations
- Accessible at any time and location to anyone with a university user account and internet connection.

To optimize the flexibility of the system, it had to be able to support all slide scanner image formats. This included z-stack slide scanning where the focus is optimized in multiple planes to show cellular details at different depths. Other image formats, including two- and three-dimensional macroscopic images, and radiology images also had to be supported as these may be used in teaching.

Shared repositories were established that could be accessed without specific setup requirements. As for all other portals

linked to the faculty servers, access to these repositories was restricted to persons with a faculty user account.

Although some classrooms are equipped with built-in desktop computers or laptops, teaching at the faculty is based on students bringing their own devices [Figure 1]. The faculty has only minimal influence on what devices the students bring to campus, and so the system had to be accessible using all computer formats and platforms, including Windows-, iOS-, and Android-based computers, smartphones, and tablets. The Irish company PathXL was chosen from a shortlist of suitable system providers, and the VIRMIK platform has been developed and optimized for use at UCPH since 2012.

Figure 1: Students are encouraged to bring their own laptops (a-c), but some classrooms have computers built in the tables, as seen in the lower right photo (d). Students can view digital specimens on the computer and make notes on their laptops

VIRMIK construction and structure

The VIRMIK service was built using a number of virtual Windows servers and VMware, which is the industry standard. The design included distributed file system (DFS) links that enable users to upload slides from a domain PC using standard internet browsers. For security reasons, the Faculty servers are located on a protected network with no direct user access, so a DFS link was used to access the repository storing the digital slides. User administration is based on a Windows domain active directory structure [Figure 2].

Each department and research group has its own operating methods. The VIRMIK service was divided into a number of Topics (i.e., subjects), and for each topic three different levels of user were established: Slide owners, instructors, and students. All published slides can be viewed by anyone with a valid university user account and an internet connection, and there is no need to be connected to the campus network.

The following is a brief technical description of how the service was set up: A database server was separated from the main web server to enhance the system's performance, and the slide scanners were connected to two image hubs. One web server was set up for presentations and required user login details via Microsoft Active Directory [Figure 2]. All servers were virtual and based on a vSphere platform. The database server, image hubs, and other resources differed in processing power and memory size. The web server was

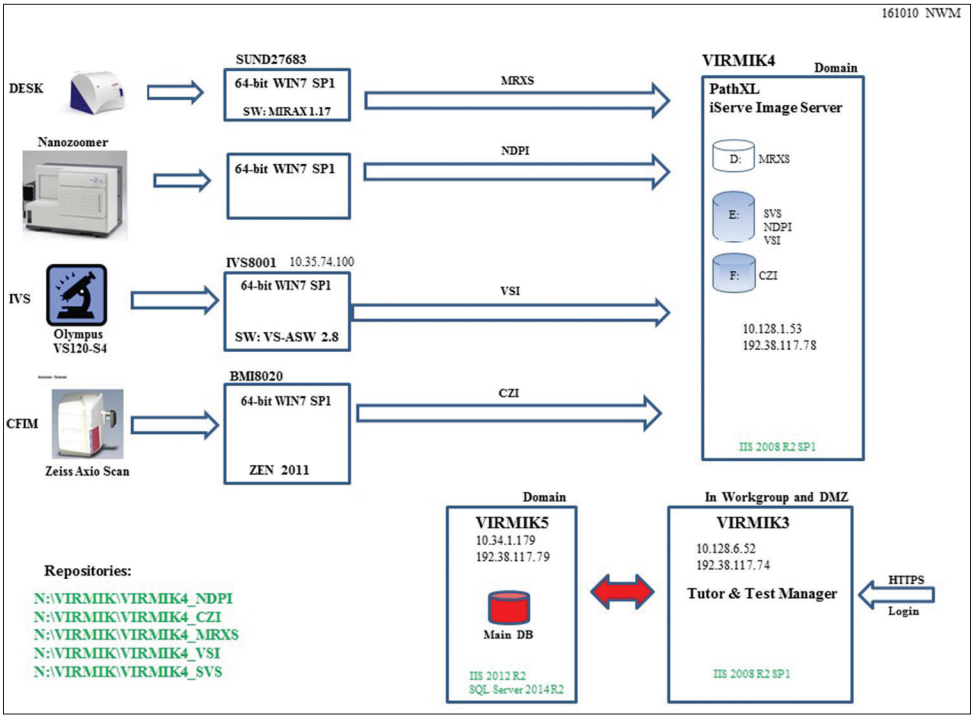

Figure 2: Schematic outline of the VIRMIK system. The slide scanners are connected to two image hubs involved in integration. A database server that is separate from the general web server boosts performance. One web server was set up for presentations and required user login details via Microsoft Active Directory

capable of accommodating login spikes, which occur at the beginning of examinations when approximately 250 students may login simultaneously. For security reasons the server network is separated into different security zones. All alterations to the system followed the Information Technology Infrastructure Library (ITIL; version 3; AXELOS, London, UK) changes model. A more detailed description is available upon request.

Snapshot copies of all system servers are made four times per day, including a backup of all scanned slides. In addition, "long-term" copies are made to a backup site once-daily.

The VIRMIK platform currently supports whole slide image files from the Mirax scanner (.mrxs-format) in addition to the .ndpi-format provided by the Hamamatsu NanoZoomer (Hamamatsu, Hamamatsu City, Japan), the. czi format from the Zeiss Axio Scan (Carl Zeiss Jena GmbH, Jena, Germany), and the. vsi-format generated by the Olympus VS120 scanner (Olympus, Tokyo, Japan).

Teaching resources

For the general pathology course, explanatory text and annotations are provided for each digital slide. The text is positioned alongside the corresponding slide thumbnail, allowing students to read the relevant information before viewing the microscope slide. The explanatory text provides comprehensive background information, making it easier for students to prepare for lessons. The annotations describe normal structures, providing information on the healthy tissue, and they also highlight abnormal structures to help the students identify histopathological changes. Examples of the explanatory text and annotations are provided in Figure 3.

To make it easier for both students and teachers to navigate the large collection of microscope specimens, each general pathology topic is subdivided into folders containing the material for each of the microscopy lessons. Teachers can make their own folders when preparing lessons and copy existing slides into these new folders, generating new explanatory text and annotations as necessary.

The VIRMIK Testing Environment

Written examinations

The digital slides have been used successfully in examinations. They can be used in different ways to test the students' knowledge, and several examples of this are provided below. Testing can include formative and/or summative assessments, and both can be accommodated by the VIRMIK setup.

The Microscopic and Macroscopic Anatomy course examination previously included a theory assessment based on describing microscope specimens, questions on macroanatomy, and a spot test. The spot test used 12 microscopes, each with two specimens. The students were given 3 min at each microscope to make a diagnosis and answer specific questions that might include naming a particular cell type shown, for example. Because this spot test was an oral exam, it was time-consuming and a drain on resources. Using the digital specimens has meant it is now possible to include the spot test in the written examination by replacing annotation text with specific questions. The students log into VIRMIK in a shielded mode allowing them to see only the specimens selected for that particular examination.

In general pathology, the written examination includes seven or eight essay questions and ten multiple choice questions, each with five possible answers. The essay questions focus on microscopy, theory and the link between microscopy, theory, and their clinical application. Microscope slides taken from two of the four major general pathology topics are supplied. With the new system, the two digital slide images can be selected from the teaching collection and annotations highlighting specific areas for the students to name or discuss may be added. These annotations can be different from the explanatory annotations used in the teaching slide set.

Including the digital slides in examinations has enabled testing to become more flexible and consistent with teaching in the classroom. Because the technology used during classroom teaching and examinations is identical, the students can learn how to perform microscopy using a single method.

Self-testing

The VIRMIK platform ensures that students can revise at home exactly what they have been taught in the classroom. In addition, in the general pathology course, short quizzes based on PathXL's online test platform are provided for students to test their knowledge. These tests use the VIRMIK specimens and annotations presented in the classroom. One quiz tests the students' ability to pan and zoom in on a specimen with questions that require a broad understanding of how a tissue might change, while other tests are based on screenshots of annotations of all 63 digital specimens. The questions are multiple choice, and each has five possible answers to choose from.

These are not preexamination tests but are designed to supplement practical classroom teaching, lectures, and case studies. Each student's score is reset when they log out allowing them to take the test before, during, and after a particular subject has been taught. As a result, they provide a type of formative testing in contrast to the summative assessments used during final examinations.

Practical Issues

The transition phase

Implementing the VIRMIK digital microscopy platform meant that teachers and students had to adapt to a novel teaching platform and new equipment as well as changes in the curriculum. In addition, classrooms had to be renovated to support the new teaching methods. High definition monitors, touch boards, and color- and light-sensitive projectors optimized for showing microscopic tissue images all had to be installed. Computers and internet connections had to be upgraded to allow many students to perform virtual microscopy at the same time, as often more than 100 students may be using the wireless LAN and VIRMIK systems simultaneously.

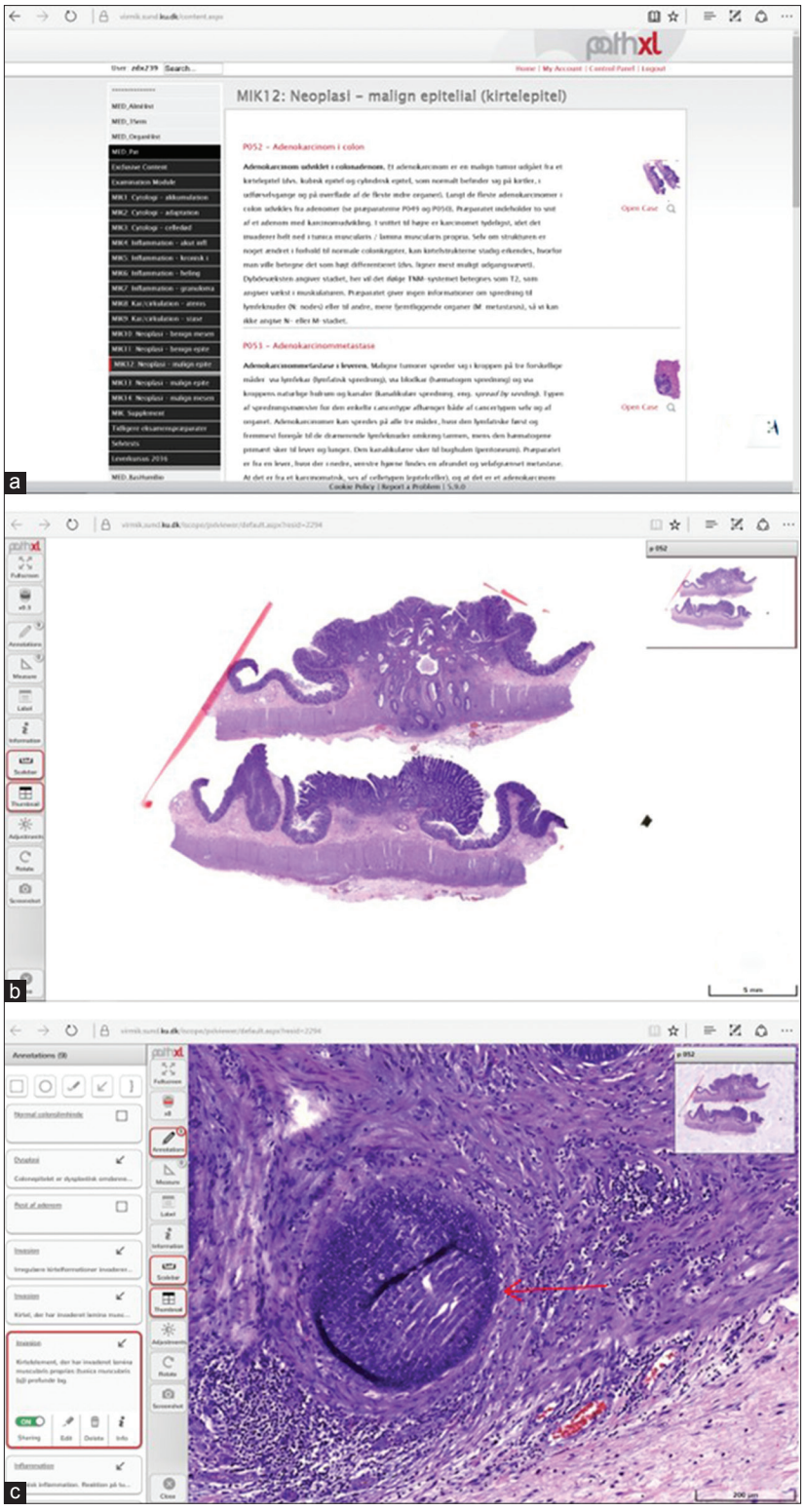

Figure 3: (a-c) Screenshots of the latest PathXL viewer in the VIRMIK virtual microscopy platform (available from April 2016). The viewer is accessible from laptops, desktop computers, tablets, or smartphones. In (a) each course is shown as a gray "title" and these can be used to access the virtual microscopy specimens. The black "titles" are subdirectories of the general pathology course and divided into subtopics: there is one for each microscopy lesson. On the right of panel a the explanatory text is shown with the corresponding microscope specimen visible as a thumbnail. The software allows the students to insert annotations and save images on their own computers; they can insert examples of any abnormalities in their personal notes using the "screenshot" button visible near the bottom of panel b. The other buttons include measurement, rotation, and zoom controls. In screenshot c, the annotations are shown, and one of these is bordered by a red frame on the left of the panel. On the image itself, the annotated feature is indicated by a red arrow

The transition from conventional microscopy and boxed glass slide collections was accomplished in different ways. Some course leaders chose to scan their existing slide collection directly, copying the entire course. This was the approach chosen by the organ histology course. The general pathology course leaders took the opportunity to renew their specimen collections and update the content of their microscopy lessons.

It also became possible to include rare specimens that could not be produced as 120 duplicate slides using the previous individual slide preparation method. As a result, it was now possible to include immunoreactions and specimens of small structures that were not big enough to produce the number of sections required in the past.

Positive feedback from students using the virtual microscopy platform meant that the technology was introduced gradually to other courses. This often involved retaining the option of analog microscopy alongside the implementation of the new digital technology. This fostered a smooth transition, enabling course directors to assess feedback and ensure all teachers were comfortable using the novel digital platform.

Technical advantages of the new system from a student perspective

The general pathology course administrators conducted surveys to assess student perceptions of the digital teaching platform and these included specific questions on virtual microscopy (unpublished data). All of the feedback was positive, with students emphasizing the easy access to the teaching resources and the flexibility that the 24-h VIRMIK platform affords. The fact that students no longer needed to attend physical microscopy study halls that had restricted opening hours was repeatedly pointed out. The explanatory text and annotations alongside each virtual microscope slide provide a better overview of the syllabus and a good basis for notetaking, according to some students. This highlights the benefit of presenting virtual microscopy specimens with explanatory text and annotations as teaching-support elements.

Administrative and economic considerations

In 2012, the Faculty of Health and Medical Sciences was established as the result of a merger within the university between the medical faculty, the pharmaceutical faculty, and the School of Veterinary Medicine. A new plan for teaching and education was launched that included a focus on better use of information technology. One aim was to facilitate digital testing, and it was decided to create a digital version of all existing histological samples so these could be used in examinations. During the initial phase and the transitional period (2010–2012), the resources required were approximately 1.5 full-time equivalent (FTE), and the capital expenditure was approximately 700,000 DKK. After the transition, the resources allocated to the new system and early online support were reduced to 0.6 FTE and approximately 800,000 DKK per year.

Over the following 2 years, all medical teaching using histological samples was transformed from microscope-based technology to virtual, digital technology. As expected, the investment in new technology was offset by significant reductions in course running costs. The VIRMIK system has subsequently been introduced to the veterinary medicine and odontology teaching programs without significant additional investment.

An additional consideration was the greater flexibility and utility of classrooms that the new system afforded. When analog microscopes were no longer needed in these classrooms, more of them became available for pathology and histology teaching.

Organization and Administrative Structure

At UCPH's Faculty of Health and Medical Sciences, study programs are administered by Faculty staff and directed by the dean. A full study program includes a collection of topics constituting a bachelor's and master's degree. The faculty currently has six full study programs in addition to six 2-year MSc programs and six 2-year professional master's programs. Danish University legislation stipulates that study boards, containing an equal representation from teachers and students, are responsible for defining the curriculum and approving the plans for teaching. With approximately 4000 enrolled students in 2015, medicine constitutes the largest single study program and has approximately 50% of the students enlisted at the faculty.

During the pilot study, VIRMIK was developed by the Department of Biomedical Sciences, which provided the course in general pathology. An IT project leader was assigned by the Faculty IT department and a small steering committee was appointed consisting of the project leader, the head of the IT Department, and course directors from three courses pioneering the use of digital microscopy. In addition, all users of VIRMIK were invited to biannual meetings.

It was essential that the introduction of VIRMIK was supported by the medical studies board because medical students receive the most extensive histology and histopathology teaching. Therefore, results from the VIRMIK pilot phase were presented to the medical studies board, who voted in favor of implementing the program. However, after debating the issue, the study board decided to retain a minimal teaching capacity in using the classical light microscope, restricted to two lectures during the first semester. Accordingly, fifty microscopes were kept and maintained while 125 were removed from service. The Director of Medical Studies coordinated these changes in collaboration with other study program directors from the courses that used light microscopy to ensure that the alterations could be accommodated by affected staff and students.

Impact on Teaching

The transition from conventional to virtual microscopy presented certain challenges for teachers. Both the methods of preparing and delivering lessons changed. However, these changes were generally positive. For example, teachers could now prepare lessons at home on a personal computer without requiring access to an analog microscope. In addition, there was no longer any time-consuming, hands-on microscope work during lessons and this created more time for reviewing specimens with the students.

The VIRMIK system provided a reliable digital platform that enabled each teacher or course director to customize a collection of scanned slide specimens to suit their particular needs. Teachers regarded this flexibility as a very positive aspect of virtual microscopy. However, the positive feedback on VIRMIK, provided by students in their written assessments at the end of each course, was the most significant factor in persuading teachers of the merits of the system.

The explanatory text associated with each image on the system has proved particularly beneficial for new teachers. The VIRMIK texts and annotations have helped to introduce teachers learning the syllabus to the subject matter. Another benefit for teachers is that the VIRMIK platform can exchange images, making it easy to optimize teaching resources and include rare examples of cytology or disease specimens without the need to generate more than 100 samples showing a particular abnormality.

Implementing VIRMIK has also made it easier to integrate new teachers. The explanatory text and annotations have helped these new recruits to understand individual specimens and how they relate to each subtopic and the curriculum as a whole. The clinical aspect of many of the explanatory texts has been particularly beneficial for those learning to teach general pathology without a medical background, as clinical considerations were not part of their academic training.

Teachers' Perceptions of the Virmik Platform

As described in reports on digital microscopy teaching from other institutions,[3,15,22-24] the VIRMIK platform has been extremely well received at the faculty. It has quickly become a central element of teaching and the explanatory texts associated with each slide are now included as part of the curriculum together with the course textbooks. These explanatory texts and annotations are invaluable guidelines for new teachers and provide common learning goals for the curriculum, ensuring optimal alignment between the syllabus, teaching, and examinations.

A further advantage of using digital specimens is that teachers no longer have to spend time locating structures and cells under a microscope and can instead focus their attention on teaching students.[2,4,6,15,19,20]

The development and implementation of virtual microscopy at UCPH has encouraged other medical schools in Denmark to use it for teaching undergraduate pathology. In most of these cases, however, less flexible, hosted systems were provided by virtual microscopy software vendors. In addition, virtual microscopy is now being used in the specialized courses that are obligatory for pathology trainees, replacing the boxed slide collections previously distributed by mail.

Students' Perceptions of the Virmik Platform

From the very beginning, students have had a positive view of digital education. For many years, the possibility of providing students with all the information they need electronically has been an idealized concept. However, implementing the digital elements of individual courses remains challenging. One obstacle is teachers, who believe that the traditional teaching methods are best.

With the VIRMIK system, we engaged the students on their own ground, using methods they were familiar with applying for many other purposes. This was certainly one of the reasons for the students' positive attitude toward the digital system. The Faculty gauged each course using student surveys collected immediately after examinations. However, in the general pathology course, an internal survey focusing on issues specific to pathology teaching is also performed. The students complete this survey before their written examinations. This particular survey revealed a very positive attitude toward the VIRMIK system and other electronic initiatives. The positive attitude was reflected in the statement that up to 15% of one semester's students considered pathology as their future career.

In addition, the students regarded VIRMIK and the other digital initiatives as extremely helpful throughout the semester, particularly when preparing for exams. Their feedback included the comments: "Great virtual microscopy system – has been a great help during the studies" and "fantastic and innovative course wonderful with online-streaming, videos and virtual microscopy. You have really created a great platform for excellent teaching." Their enthusiasm for digital microscopy is consistent with reports from other institutions.[3,4,6,8,15,19,20,22-26]

Alignment With Diagnostic Pathology

The implementation of digital microscopy methods in routine diagnostic pathology is outside the scope of this article, but it is important that medical schools are aware of technological developments likely to occur in the near future and can present these to their students. Digital pathology procedures that include virtual microscopy, the use of databases, and electronic reporting are currently being implemented in a number of pathology departments across the world.[11,27-29] Digital pathology methods have already been used for frozen section diagnostics between cooperating hospitals in different locations, for example between a neurosurgical unit in one location and a pathology department in another, as in a recently reported collaboration between units in

Toronto and New York.[30-32] This can make it unnecessary for a specialist pathologist to travel from their office at one hospital to the surgical unit at another to assess emergency tissue biopsies during surgery. In the Department of Pathology at Copenhagen University Hospital Rigshospitalet, digital methods have enabled pathologists working at their homes, in the Netherlands for example, to be employed performing diagnostic pathology via online server connections. In addition, biomarker assessment can be performed using digital image analysis, rapidly providing verifiable, high-quality results for cancer patients. These advances clearly require particular server and scanner configurations, but they do demonstrate the potential of digital pathology and suggest that the health-care system can benefit from investing in early training in its application.

During the last 2 years, digital pathology has significantly advanced toward becoming a routine procedure. For example, medium-sized hospitals in Utrecht and Hengelo in the Netherlands, and in Linköping in Sweden, have replaced conventional microscopy with the digital approach, scanning all their glass slides and storing them on a server accessible to diagnosing pathologists.[14,33] In other cases, for example, the pathology department at Odense University Hospital in Denmark, scanning is only used for storage and not as part of the initial diagnostic procedure. However, a database of stored images is a valuable resource for comparing fresh biopsies with those assessed earlier in the patient's disease history. The large university hospital pathology department at Rigshospitalet in Copenhagen receives more than 95,000 tissue samples (excluding vaginal smears) and produces more than 800,000 glass slides annually. Here, the process of completely replacing conventional microscopy with a virtual system is ongoing and expected to be complete by 2020.

In Denmark, patients have become increasingly interested in accessing their medical and hospital records. This includes tissue specimens removed to make a diagnosis or as part of surgical intervention. It is unlikely to be feasible or prudent to link virtual microscopy specimens to patient files and allow patients to access raw scans. However, allowing patients to see still photos with annotations highlighting diagnostic abnormalities may be a viable alternative. A closer link between patient files and virtual images might benefit clinicians, facilitating a better understanding of the changes that have occurred in individual patients.

Although the details are uncertain, digital platforms that include virtual microscopy will undoubtedly be important for the diagnostic pathologist of the future. As a result, devoting large amounts of resources to sustaining teaching in the use of conventional microscopes is difficult to justify. In cases where three-dimensional aspects of a specimen need to be assessed (e.g., depth in a thick cytological specimen or live microorganisms) conventional microscopy can be taught as part of the specialist training. However, the rapid progress in the technology associated with digital methods over the past few years suggests that future scanners may also be able to meet these requirements.

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There are no conflicts of interest.

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