Hortsch Michael (Orcid ID: 0000-0002-3750-737X)

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Descriptive Article

Serving Learners and Educators Worldwide: The Michigan Histology Website as an Example for a Free Anatomical Resource

Michael Hortsch[1,2]

[1]Department of Learning Health Sciences, University of Michigan Medical School, Ann Arbor, Michigan

[2]Department of Cell and Developmental Biology, University of Michigan Medical School, Ann Arbor, Michigan

Running title: Managing a free educational histology website

Correspondence to: Dr. Michael Hortsch, Department of Cell and Developmental Biology, University of Michigan Medical School, 109 Zina Pitcher Place, Ann Arbor, MI 48109, USA. E-mail: hortsch@umich.edu

ORCID ID:

Michael Hortsch: https://orcid.org/0000-0002-3750-737X

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ABSTRACT

With anatomical education becoming a global endeavor, free online resources offered via the internet or other electronic venues are of increasing importance for teaching and learning communities worldwide. Students and instructors from developing countries, often limited in access to modern instructional resources by infrastructural and financial constraints, are frequent users of such online learning tools. During the recent Covid-19 pandemic when all academic institutions were forced to quickly switch to a non-contact mode of teaching, free online instructional resources were often essential for continuing the educational mission. However, there are a number of obstacles and issues that need to be considered when creating and offering such learning resources. These include the type, quality, and completeness of the content, their educational purpose, access to technical and financial resources, copyright and ethical issues, and more. Educators, who plan to generate and maintain free online resources, should also be aware that such projects usually require a considerable long-term time commitment. In this paper, these issues are discussed using the Michigan Histology website as an example. The discussion also addresses how e-learning resources like the Michigan Histology website supported online learning during the recent Covid-19 pandemic.

Keywords: e-learning, histology education, microscopic anatomy education, internet, global education, virtual microscopy, histology resources,

INTRODUCTION

E-learning resources, especially those ubiquitously available on the internet, have claimed an increasing role in today's medical education environment (Ellaway and Masters, 2008). The educational potential of the internet or World Wide Web (WWW) was realized early in the 1990's when this new tool for disseminating information became widely available (Rajendran, 2001). The current generation of learners grew up with computers and the internet and educators often assume that they are familiar with these resources and will embrace them (Proserpio and Gioia, 2007; Talmon, 2019). However, more recent analyses indicate that the acceptance of e-learning resources by students depends on a variety of factors, like convenience of use, easy availability, familiarity with the technology, and a perception that it provides an advantage to the learner (Wong et al., 2010; Bringman-Rodenbarger and Hortsch, 2020; Finn et al., 2022). In addition, a well-defined educational purpose and good overall design are central for the success of an e-learning tool (Chu and Chan, 1998; Masters and Ellaway, 2008).

A growing number of internet sites offer educational material for learning gross anatomy, neuroanatomy, histology, and embryology. These internet resources include educational websites (Alsup and Fox, 2022; Gobée, 2022; Table 1), video recordings (Chapman, 2013; Barry et al., 2016; Yohannan et al., 2022), social media (Maske et al., 2018; Chytas, 2019; Pollock and Rea, 2019), mobile applications (Hortsch, 2016; Ostrin and Duschenkov, 2016; Rujano-Balza, 2021), podcasts (Beylefeld et al., 2008; FeedSpot, 2022), and more. Professional societies also offer educational databases for their members and often non-members (ASCB, 2022; Goldman et al., 2022). These free

educational tools are complemented by a growing number of commercial medical education resources that are popular with professional students, especially when they prepare for licensing examinations (Banos et al., 2018; O'Hanlon and Laynor, 2019; Finn et al., 2022).

As the internet provides a great vehicle for supporting the switch from the use of traditional light to virtual microscopy for the teaching of histology (Hortsch 2013; Parker et al., 2017; Chapman et al., 2020; Sharmin et al., 2021), websites and virtual image databases play a special role in this transition (Lee et al., 2018). Table 1 provides a list of free histology websites with virtual microscopy images. In addition, several reports indicate that the use of virtual microscopy for the teaching of histology allows for a more active and collaborative style of learning (Triola and Holloway, 2011; Bloodgood 2012). The migration of histology laboratory instruction to an online delivery modus is sometimes supplemented with recorded histology lectures that are available from computer servers or the internet (Selvig et al., 2015; Saverino et al., 2022). Even before the Covid-19 pandemic restricted in-classroom activities, histology courses at some institutions had been either partially or entirely transferred to an online format (Barbeau et al., 2013; Gadbury-Amyot et al., 2013; Yen et al., 2014; Thompson and Lowrie, 2017; Gribbin et al., 2022). These changes reflect a larger movement in medical education of making educational material available to students at times and locations of their choice (Harden, 2005; Ruiz et al., 2006).

Most websites offering learning resources originate from highly industrialized countries (Table 1). Educators from developing countries often do not have the technological and financial resources to create and provide these tools to their learners (Barteit et al.,

2020). However, as the internet allows for the global distribution of educational material, learners in these countries usually have better access to them. Nevertheless, there are considerable global inequities in the utilization of online education resources, as infrastructural problems often prevent or slow down the use of internet-derived learning tools in less industrialized countries (Williams et al., 2010). In addition, the type and abilities of personal devices that are available to learners in these global regions may limit their effective use (Rusatira et al., 2016; Mayes et al., 2017). In addition, commercial sites offer access to virtual light micrographs (LMs) and electron micrographs (EMs) that are suitable for histology/microanatomy instruction. However, unless these for-profit tools are provided by the school, such learning resources can be expensive and may not be affordable for many students and educators in less affluent countries or strata of society (Vafa and Chico, 2013; Finn et al., 2022).

The development of free e-learning resources for anatomy or histology that will be popular with students and support the intended learning goals can be a daunting task and a number of non-educational issues also need to be addressed. This article describes the Michigan Histology website, using it as a paradigm for outlining the problems and issues that should be considered when creating and offering an open educational website or other free e-learning tool. It also touches on the importance of learning resources like the Michigan Histology website during the recent Covid-19 pandemic.

DESCRIPTION

Description of the Michigan Histology website and its use at the University of Michigan

The Michigan Histology website is a free educational tool that supports histology learners at the University of Michigan (UM) and at any location with access to the internet (UMMS, 2022; Figure 1). The website's original version went online in 2006 when histology laboratory instruction at the UM switched from traditional light microscopes with glass slides to virtual microscopy. At that time students were using the website with its virtual slides during faculty-guided histology laboratory sessions. Currently, it serves first year dental and medical students during their histology training, and it also supports an undergraduate/graduate histology course offered by the author to all UM students (Zaidi et al., 2017). Today, these courses no longer include scheduled faculty-guided laboratory sessions. Therefore, the Michigan Histology website is the only opportunity for UM students to engage with histology slide material in these curricular components or courses (Johnson et al., 2015; Zaidi et al., 2017; Gribbin et al., 2022). The current website version offers 268 unlabeled virtual light microscope images (at a maximal magnification equivalent to a 20X or 40X objective) and 140 labeled transmission electron micrographs (TEMs). The majority of light microscope specimens are stained with Hematoxylin & Eosin (H&E) (70.9% of all light microscope slides) or Masson's trichrome stain (14.6%). A few specimens were treated with Periodic Acid-Schiff (PAS) (1.9%), luxol fast blue (1.9%), silver (1.1%, or other histological stains (9.7). These virtual slides are supplemented by numerous static images often derived from the virtual slides that depict specific histological structures as examples and to help users when locating equivalent cells and structures in the

unlabeled virtual slides. Since the establishment of the Michigan Histology website in 2006, a number of virtual slides were added, several obtained with the appropriate permission from non-UM colleagues. They either replaced older slides of lower image quality or filled gaps in the existing Michigan virtual slide collection. In 2011, all EM micrographs on the website were replaced with new, higher resolution scans of labeled transmission electron micrographs (TEMs). These TEM images originated from the laboratory of a former chair of the UM Anatomy Department (now Cell and Developmental Biology), Dr. Johannes Rhodin (1922-2004), who donated them for educational purposes when he left the University of Michigan in 1977.

In the current version of the website, the major tissues and organs that are usually covered in a professional school histology course/component are represented in 28 different modules/subpages that are arranged according to the schedules of the three histology courses/components/sequences at the University of Michigan. Each module/subpage opens with learning objectives and concludes with several review and sample test questions (MCQs) that allow students to test their knowledge and recognition skills. The body of each module/subpage includes histology laboratory instructions with links to the virtual microscope images and a short list of links to and descriptions of labeled TEM micrographs. The original website was based on and replaced a previous printed laboratory manual provided to UM students enrolled in a histology course/segment together with a loan light microscope and a histological glass slide collection. After the Michigan Histology website with its virtual slides came online in 2006, loan light microscopes and glass slide sets were still offered upon request to medical students. Until faculty-guided laboratory sessions were abolished for medical

students in the 2026-2017 academic year, fewer than 10 out of over 1,700 medical students checked out a loan microscope with glass slide collection. In summary, the website serves a very specific educational purpose, guiding students through histology laboratory sessions with an assortment of virtual slides and images.

Originally, students accessed the website during faculty-guided laboratory sessions. As the website allows students to study histology slides independently of scheduled laboratory hours at their own choice of time and location, fewer and fewer students participated as their attendance was non-mandatory (Holaday et al., 2013). Interestingly, students, who attended these faculty-guided laboratory sessions, scored significantly better in histology assessments (Selvig et al., 2015). The reluctance of many UM students to attend faculty-guided histology laboratory sessions may have been a contributing factor in their cancelation when a new medical curriculum was introduced at the UM Medical School for the 2015-2016 academic year (Daniel et al., 2020; Gribbin et al., 2022). This change of format made the Michigan Histology website the main learning resource for histology learners at the UM for acquiring analytical recognition skills of normal tissues and organs at the microscopic scale. Faculty-guided histology laboratory sessions for dental students had already been discontinued 10 years earlier and were replaced with self-study of the Michigan Histology website.

Global use of the Michigan Histology website

The Michigan Histology website is an open resources that can be accessed worldwide by any person with an active internet connection. Figure 2 displays Google Analytics numbers (Google LLC., Mountain View, CA; Ledford et al., 2009) of monthly sessions

and users for the Michigan Histology website, from September 2016 to June 2022. Access to the site follows a seasonal pattern that mirrors the academic calendar used in many countries with two minima for sessions and users in the months of June to August and in December and January corresponding to summer and holiday breaks, respectively. During the almost six-year time period shown in Figure 2, the Michigan Histology website had monthly averages of 46.8k sessions and 30.8k users. In pre-Covid-19 pandemic time period (September 2016 to March 2020), session and user numbers exhibited consistent moderate yearly increases (<12% from year to year; Figure 2). According to the available Google Analytics data, these website sessions originated from 227 different countries and territories located on all seven continents (on average 167 different countries/territories each month). Most website visitors were located in the US, followed by users from India, the Philippines, the United Kingdom, Australia, Canada, Colombia, Brazil, Mexico, and other nations. It is noteworthy that several of these countries are non-native English-speaking. Occasionally, the author has received emails from histology instructors at other institutions stating that they recommend the Michigan Histology website to their learners as a supplementary learning resource. Users from the State of Michigan made up an average of 2.3% of all website users. However, not all Michigan users may be UM students and especially during the Covid-19 pandemic some UM students may have accessed the website from out-of-state locations.

Use of the Michigan Histology website during the Covid-19 pandemic

The number of sessions and users of the Michigan Histology website increased moderately in pre-pandemic years (Fig. 2). The years 2018 and 2019 exhibited increases of 11.9% and 0.3% in the number of sessions when compared to the respective previous years (Fig. 2). In comparison to the previous year, for the Covid-19 years 2020 and 2021 the number of sessions increased by 26.7% and 24.2%, respectively. It is too early to determine whether with the pandemic ending these trends will remain or are changing. Initial session and user numbers for 2022 indicate a reduction in the number of sessions and users for the Michigan Histology website when compared to the 2021 pandemic year (Fig. 2). However, these numbers still exceed pre-pandemic years. This might indicate that at least some schools are returning to classroom laboratory histology instruction, thereby reducing the overall global need for online histology laboratory resources like the Michigan Histology website. More long-term data are required to confirm or disprove these preliminary observations.

DISCUSSION

General considerations when planning and creating a free e-learning resource

The creation of modern e-learning resources not only requires technical know-how, but often also financial support. Not all educators have the technical expertise to independently create functional new e-learning resources like a website, computer program, or mobile application and hiring outside contractors for such a project usually requires considerable financial resources. It is also expensive to include drawings and diagrams that are custom-made by professional artists. Obtaining an institutional or foundation grant for financing an educational development project is one option

(Gruppen and Durning, 2016). However, medical education grants usually have a limited budget and will rarely support the long-term upkeep of the new resource. An alternative option is to develop the new resource as part of the existing educational program at an educational institution. Following that strategy, the original version of the Michigan Histology website was developed as a replacement for light microscopes and glass slide boxes used previously for histology laboratory instruction. The digitalization of existing histological glass slides was done almost 20 years ago by several UM faculty members. Maintenance of the Michigan Histology website and access to the virtual slide collection on internal servers is currently supported by the UM Medical School's Health Information Technology and Services group (HITS) as part of the school's teaching infrastructure. No recharges for information technology (IT) personnel's time or server space are currently levied against the histology courses or the Cell and Developmental Biology Department. UM histology learners are the primary intended users of the Michigan Histology website. The website was designed to serve three different histology courses or components at the UM, dental, medical and an undergraduate/graduate histology course (Figure 1). The underlying pedagogy and purpose of the Michigan Histology website, to offer self-guided histology laboratory exercises, has not changed since its inception. When faculty-guided laboratory sessions were still offered to UM medical students (UM dental students have used the website as a self-study resource since 2006), student participation decreased over the years (Holaday et al 2013; Gribbin et al 2022), eventually resulting in the abolishment of scheduled laboratory sessions for medical histology and making the Michigan Histology website the major histology laboratory learning resource at the UM (Gribbin et al 2022).

However, the Michigan Histology website's organization may limit its appeal to outside educators and learners, whose course structure and educational priorities may be different from the author's home institution. Another limiting factor for the use of an outside website as a primary teaching resource, may be the unreliability of internet access in many parts of the world. Access may be interrupted for technical reasons, or when the owner of a website decides to discontinue or limit its availability.

An important factor for the success of an e-learning resource project is also the quality of the image material, such as specimens and images, that are available for the project. The virtual slides offered on the Michigan Histology website are derived from a large glass slide collection at the UM. However, no individual institutional resource is likely to be complete and of consistent high quality. Therefore, it is often necessary to obtain missing or better specimens from colleagues or other sources. Alternatively, missing specimens may have to be generated de novo to fill such gaps. In the author's experience, an e-learning tool that address only one specific topic and does not cover a complete course of study is often of limited use and less popular with learners. However, initially creating a smaller, more limited learning tool may be a valuable first step as a proof of concept to attract financial and logistic support for completing the project.

Technical pitfalls and speed bumps

Technological advances and software updates may sometimes require major updates of an e-learning resource. Recently, the original virtual slide viewer of the Michigan Histology website needed to be replaced as it required Adobe Flash (Adobe Systems

Inc., San Jose, CA). Since January 2021, Adobe Flash is no longer supported by internet browsers. This necessitated the reformatting of more than 400 virtual image files displayed on the Michigan Histology website to make them compatible with the new Zoomify HTML 5 Enterprise Edition (version 5) software (Zoomify Inc., Santa Cruz, CA). One other concern when offering a web-based learning resource is its vulnerability to malicious hacker attacks. The Michigan Histology website uses an open-source content management system called Drupal, which was developed and is curated by the Drupal community (Tomlinson, 2010). Unless the website is constantly updated and runs the latest software version, it may become vulnerable to hacking attacks regardless of the software used. In the past, this has happened to the Michigan Histology website on three occasions, twice resulting in a temporary shutdown of the site.

Besides major revisions, a resource like the Michigan Histology website requires ongoing minor updates and corrections. The reasons for these smaller changes are multifold, from simple typos and broken links to layout inconsistencies. Although the anatomical sciences are not quickly moving fields with frequent new insights and changing information, occasionally, the information or presentation of a specific topic will need to be updated or new images or facts have to be added. Unless a significant malfunction occurs, it is the author's experience that students rarely take the time to report minor errors or dysfunctional links to the website administrator but that non-UM colleagues sometimes report website problems to the administrator. In summary, updating and correcting an educational website or similar resource is a never-ending chore. Another issue that can limit the accessibility or lifetime of an open learning resource can be the retirement or departure of the person(s) creating or maintaining the

resource. Unless a new person is identified as being responsible for maintaining the tool and/or it is an essential part of the institution's learning environment (which has been the case for the Michigan Histology website), missing updates and services most likely will result in the ultimate demise of the resource. A transfer of responsibility for the Michigan Histology website happened in 2010 when the previous administrator moved to a different university and the author took over as website manager.

Language, legal, and ethical considerations when creating e-learning resources

Another factor that may limit the usefulness of an open educational resource for international clients is the language. Although English is today's lingua franca in most scientific fields and is also used as the instructional language at schools in non-English-speaking countries geared to serve a diverse international student cohort, the local language is often the predominant instructional vernacular in many countries and global regions. Most free instructional resources on the internet are in English and even though many students in non-English speaking countries have at least a basic level of English competency, learning resources that are not in their native tongue may not be as helpful for these learners (Sabbour et al., 2012; Alsuliman et al., 2019). Very few histology internet websites are in a language other than English (Bock et al., 2022). Despite this language limitation, the Michigan Histology website enjoys wide international use. Every year, users from over 200 countries and territories visit the site. However, whether the impact on learning differs between native and non-native English website users remains unknown.

Copyright is another important issue that needs to be addressed when creating freely available educational resources (Lyons, 2010). Copyright laws vary from country to country and there are no universal standards. For example, US copyright law makes certain limited allowances for the "fair use" of copyrighted material in a closed classroom setting. However, this does not extend to educational material that is offered unrestricted on the internet or other open venues. Therefore, using only material for which the author(s) or his/her institution holds the copyright may be the preferred solution. Otherwise, the author(s) need(s) to obtain written permission from the copyright holder. Alternatively, unrestricted material for which the copyright has expired or items that are in the public domain can be used freely. Most material from US federal agencies like the National Institutes of Health (NIH) or the Centers for Disease Control and Prevention (CDC) have been released into the public domain. Another option is the use of material that is made available by the copyright holder under a Creative Commons (CC) license (Maggio and Stranack, 2020). A CC license does not change copyright ownership but grants a limited permission to use the material as outlined by the specific CC license. These limitations often include the requirement to appropriately attribute the material to its creator or owner and often restricts use to non-commercial applications. The Michigan Histology website is offered under a BY-SA-NC (attribution-share alike-noncommercial) CC license (Creative Commons, 2022; Figure 1) and the author obtained permission for images for which the UM does not hold the copyright. These items/images are attributed to the unit/person that holds the corresponding copyright. Any other copyrighted material is available to UM students from a password-protected server. This material is not available to individuals without a UM affiliation.

Another option when creating new educational resources that will be freely available is to buy a license from a commercial supplier. Also, as copyright law is nationally defined, content creators should be aware that enforcing one's own copyright against unauthorized use in other countries is often impractical or impossible. As a further complication, students not being aware of copyright restrictions may post or upload copyrighted material that was made available to them in a university course under the "fair use" clause on open and sometimes commercial websites.

When creating new teaching resources, especially when using human specimens, other concerns, usually of an ethical nature, may arise (Hildebrandt, 2016; Hennessy et al., 2020). The author(s) should make sure that proper consent was obtained and that none of the material can be traced back to an individual or body donor. This applies not only to images, but also to patient case description and other material.

The use of the Michigan Histology website during the Covid-19 pandemic

Starting in March 2020, the Covid-19 pandemic restricted face-to-face classroom teaching worldwide (Dhawan, 2020; Van Nuland et al., 2020; Caruso 2021). Schools like the University of Michigan that had disbanded faculty-guided histology laboratory sessions previously continued to rely on online resources like the Michigan Histology website and offered recorded lecture videos to learners. Other schools that prior to the Covid-19 pandemic still offered in-person histology laboratory instruction had to find alternatives and many supplemented their histology and pathology learning resources with online tools like the Michigan Histology website or other similar material as listed in Table 1 (Cheng et al., 2021; Darici et al., 2021; dos Santos et al., 2021; Ishak et al.,

2022; Nikas et al., 2022; Saverino et al., 2022). While the pandemic restricted in-person teaching, the Michigan Histology website saw a noticeable increase in the number of sessions and users (Figure 2) and it raises the possibility that the forced change of teaching modalities contributed to that increase use of the website. It will be of interest whether the observed increase in Michigan Histology website users and visits will be maintained with the pandemic ending or whether schools will return to their pre-pandemic modes of teaching. If the recent use of the Michigan Histology website is a preliminary indication, the answer to that question will vary depending on decisions made by individual schools. A second open question is what impact switching to online learning had on students' histology knowledge and skill levels. While some reports claim an academically successful implementation of online histology teaching (Amer and Nemenquani, 2020; Darici et al., 2021), a long-term rigorous analysis of more than one school may be needed to answer this question. In the absence of solid data, many schools will have to decide whether to return to pre-pandemic type of histology laboratory instruction or continue with an exclusive online approach. Even though several studies show that virtual microscopy is an effective technology to teach histology and pathology online (Lee et al., 2020; Felszeghy et al., 2017), the argument has been made that the ability to use traditional light microscopes is still a valuable skill for today's medical professionals (Pratt, 2009; Thintharua and Dharmasaroja, 2020; Ishak et al., 2022). If students are left without any expert faculty support during their study of virtual slides, pre-pandemic experiences from the author's institution predict a decrease of students' histology learning outcomes (Selvig et al., 2015; Gribbin et al 2022). Regardless, it appears unlikely that all changes that were forced by the Covid-19

pandemic will be reversed and online resources like the Michigan Histology website will remain an important component for teaching histology in the future.

Study Limitations

This article only describes the Michigan Histology website and the author's advice and experiences with this resource may not always apply to other projects. Reasons for creating similar resources will vary at different locations, as well as conditions and institutional support for their establishment and maintenance. Access numbers for the website were obtained from Google Analytics and need to be interpreted with care. Only IP locations are tracked, and individual users may have accessed the website from more than one location, as well as several users may have shared a computer station, for example when it was located in a university computing facility. Therefore, the reported numbers for sessions and users may not be exact and only reflect relative trends in website usage. As global access to the Michigan Histology website is anonymous, the author only has limited information about the use and educational efficacy of the website from places outside his own institution.

CONCLUSIONS

Creating and running free learning resources usually requires a lot of work and a significant time investment, as well as financial and technical resources. However, it is also a gratifying endeavor, as it raises the visibility of the individual(s), and the school or organization that offer such resource. A free educational tool can also initiate new national and international contacts and possible collaborations with students and

colleagues at other schools. Finally, the educational benefits of such projects are often global and extend well beyond the author's own institution, helping educators and learners in countries where such resources are not readily available and cannot easily be created.

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NOTES ON THE CONTRIBUTOR

MICHAEL HORTSCH, Ph.D., is a professor in the Departments of Cell and Developmental Biology and of Learning Health Sciences at the University of Michigan Medical School in Ann Arbor, Michigan. Since 1991, he has taught histology to undergraduate, graduate, medical, and dental students. His main research interests are in the development and analysis of electronic teaching tools and how these resources impact students' learning. He is also a fellow of the American Association for Anatomy (AAA) and serves as an Associate Editor for FASEB BioAdvances journal.

REFERENCES

Alsuliman T, Alasadi L, Mouki A, Alsaid B. 2019. Language of written medical educational materials for non-English speaking populations: An evaluation of a simplified bi-lingual approach. BMC Med Educ 19:418.

Alsup BK, Fox GM, 2022. BlueLink. University of Michigan Medical School, Ann Arbor MI. URL: https://sites.google.com/a/umich.edu/bluelink/curricula?authuser=0 [accessed 25 September 2022].

Amer MG, Nemenqani DM. 2020. Successful use of virtual microscopy in the assessment of practical histology during pandemic COVID-19: A descriptive study. J Microsc Ultra 8:156.

ASCB. 2022. American Society for Cell Biology. Cell Image Library. Center for Research in Biological Systems. La Jolla, CA. URL: http://www.cellimagelibrary.org/home [accessed 25 September 2022].

Banos JH, Pepin ME, Van Wagoner N. 2018. Class-wide access to a commercial step 1 question bank during preclinical organ-based modules: A pilot project. Acad Med 93:486–490.

Barbeau ML, Johnson M, Gibson C, Rogers KA. 2013. The development and assessment of an online microscopic anatomy laboratory course. Anat Sci Educ 6:246–256.

Barry DS, Marzouk F, Chulak-Oglu K, Bennett D, Tierney P, O'Keeffe GW. 2016. Anatomy education for the YouTube generation. Anat Sci Educ 9:90–96.

Barteit S, Guzek D, Jahn A, Bärnighausen T, Jorge MM, Neuhann F. 2020. Evaluation of e-learning for medical education in low- and middle-income countries: A systematic review. Comput Educ 145:103726.

Beylefeld AA, Hugo AP, Geyer HJ. 2008. More learning and less teaching? Students' perceptions of a histology podcast. S Afr J High Educ 22:948–956.

Bloodgood RA. 2012. Active learning: A small group histology laboratory exercise in a whole class setting utilizing virtual slides and peer education. Anat Sci Educ 5:367–373.

Bock R, Lang I, Schmitt J, 2022. Virtuelle Mikroskopie. Saarland University, Saarbrücken, Germany. URL: https://mikroskopie-uds.de [accessed 8 July 2022].

Bringman-Rodenbarger L, Hortsch M. 2020. How students choose E-learning resources: The importance of ease, familiarity, and convenience. FASEB BioAdv 2:286–295.

Caruso MC. 2021. Virtual microscopy and other technologies for teaching histology during Covid-19. Anat Sci Educ 14:19–21.

Chapman J. 2013. Chapman Histology. Welcome to Chapman Histology. Video 2:23 min. University of Tasmania, Hobart, TAS, Australia. URL: https://www.youtube.com/channel/UCvSvCkHjCbHn8aGd6OPno_A [accessed 25 September 2022].

Chapman JA, Lee LMJ, Swailes NT. 2020. From scope to screen: The evolution of histology education. Adv Exp Med Biol 1260:75–107.

Cheng X, Chan LK, Cai H, Zhou D, Yang X. 2021. Adaptions and perceptions on histology and embryology teaching practice in China during the Covid-19 pandemic. Translat Res Anat 24:1–10.

Chu LF, Chan BK. 1998. Evolution of web site design: Implications for medical education on the Internet. Comput Biol Med 28:459–472.

Chytas D. 2019. Use of social media in anatomy education: A narrative review of the literature. Ann Anat 221:165–172.

Creative Commons. 2022. Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0). Creative Commons. Mountain View, CA, USA. URL: https://creativecommons.org/licenses/by-nc-sa/4.0/ [accessed 25 September 2022].

Daniel M, Monrad SU, Weir S, Kolars JC, Mangrulkar RS. 2020. University of Michigan Medical School. Acad Med 95:S249–S253.

Darici D, Reissner C, Brockhaus J, Missler M. 2021. Implementation of a fully digital histology course in the anatomical teaching curriculum during COVID-19 pandemic. Ann Anat 236:151718.

Dhawan S. 2020. Online learning: A panacea in the time of COVID-19 crisis. J Educ Technol Syst 49:5–22.

dos Santos FS, Osako MK, Perdona GD, Alves MG, Sales KU. 2021. Virtual microscopy as a learning tool in Brazilian medical education. Anat Sci Educ 14:408–416.

Ellaway R, Masters K. 2008. AMEE guide 32: e-Learning in medical education Part 1: Learning, teaching and assessment. Med Teach 30:455–473.

FeedSpot. 2022. 25 Best human anatomy and physiology podcasts. FeedSpot, Mill Valley, CA. URL: https://blog.feedspot.com/human_anatomy_podcasts/ [accessed 25 September 2022].

Felszeghy S, Pasonen-Seppänen S, Koskela A, Mahonen A. 2017. Student-focused virtual histology education: Do new scenarios and digital technology matter? MedEdPublish 6:154.

Finn E, Ayres F, Goldberg S, Hortsch M. 2022. Brave new e-world: Medical students' preferences for and usage of electronic learning resources during two different phases of their education. FASEB Bioadv 4:298–308.

Gadbury-Amyot CC, Singh AH, Overman PR. 2013. Teaching with technology: Learning outcomes for a combined dental and dental hygiene online hybrid oral histology course. J Dent Educ 77:732–743.

Gobée OP, 2022. AnatomyTool. Leiden University Medical School. Leiden, The Netherlands. URL: https://anatomytool.org [accessed 25 September 2022].

Goldman HM, Hortsch M, Lee LM, 2022. Virtual Microscopy Database. American Association for Anatomy, Rockville, MD. URL: https://www.virtualmicroscopydatabase.org [accessed 25 September 2022].

Gribbin W, Wilson EA, McTaggart S, Hortsch M. 2022. Histology education in an integrated, time-restricted medical curriculum: Academic outcomes and students' study adaptations. Anat Sci Educ 15:671–684.

Gruppen LD, Durning SJ. 2016. Needles and haystacks: Finding funding for medical education research. Acad Med 91:480–484.

Harden RM. 2005. A new vision for distance learning and continuing medical education. J Contin Educ Health Prof 25:43–51.

Hennessy CM, Royer DF, Meyer AJ, Smith CF. 2020. Social media guidelines for anatomists. Anat Sci Educ 13:527–539.

Hildebrandt S. 2016. Thoughts on practical core elements of an ethical anatomical education. Clin Anat 29:37–45.

Holaday L, Selvig D, Purkiss J, Hortsch M. 2013. Preference of interactive electronic versus traditional learning resources by University of Michigan medical students during the first year histology component. Med Sci Educ 23:607–619.

Hortsch M. 2013. From microscopes to virtual reality - How our teaching of histology is changing. J Cytol Histol 4:e108.

Hortsch M. 2016. Taking a SecondLook™ at a time-efficient self-review resource. Med Sci Educ 26:3–4.

Ishak A, AlRawashdeh MM, Meletiou-Mavrotheris M, Nikas IP. 2022. Virtual pathology education in medical schools worldwide during the COVID-19 pandemic: Advantages, challenges faced, and perspectives. Diagnostics (Basel) 12:1578.

Johnson S, Purkiss J, Holaday L, Selvig D, Hortsch M. 2015. Learning histology - Dental and medical students' study strategies. Eur J Dent Educ 19:65–73.

Ledford J, Teixeira J, Tyler ME. 2009. Google Analytics, 3rd Ed. Indianapolis, IN: Wiley Publishing Inc. 448 p.

Lee BC, Hsieh ST, Chang YL, Tseng FY, Lin YJ, Chen YL, Wang SH, Chang YF, Ho YL, Ni YH, Chang SC. 2020. A web-based virtual microscopy platform for improving academic performance in histology and pathology laboratory courses: A pilot study. Anat Sci Educ 13:743–158.

Lee LM, Goldman HM, Hortsch M. 2018. The virtual microscopy database-sharing digital microscope images for research and education. Anat Sci Educ 11:510–515.

Lyons MG. 2010. Open access is almost here: Navigating through copyright, fair use, and the TEACH Act. J Contin Educ Nurs 41:57–64.

Maggio LA, Stranack K. 2020. Understanding creative commons. Acad Med 95:322.

Maske SS, Kamble PH, Kataria SK, Raichandani L, Dhankar R. 2018. Feasibility, effectiveness, and students' attitude toward using WhatsApp in histology teaching and learning. J Educ Health Promot 7:158.

Masters K, Ellaway R. 2008. e-Learning in medical education Guide 32 part 2: Technology, management and design. Med Teach 30:474–489.

Mayes J, White A, Byrne M, Mogg J. 2017. How smartphone technology is changing healthcare in developing countries. J Global Health 7:36–38.

Nikas IP, Lamnisos D, Meletiou-Mavrotheris M, Themistocleous SC, Pieridi C, Mytilinaios DG, Michaelides C, Johnson EO. 2022. Shift to emergency remote preclinical medical education amidst the Covid-19 pandemic: A single-institution study. Anat Sci Educ 15:27–41.

O'Hanlon R, Laynor G. 2019. Responding to a new generation of proprietary study resources in medical education. J Med Libr Assoc 107:251–257.

Ostrin Z, Duschenkov V. 2016. The pedagogical value of mobile devices and content-specific application software in the A&P laboratory. HAPS Educ 20:97–103.

Parker EU, Reder NP, Glasser D, Henriksen J, Kilgore MR, Rendi MH. 2017. NDER: A novel web application for teaching histology to medical students. Acad Pathol 4:2374289517691061.

Pollock W, Rea PM. 2019. The use of social media in anatomical and health professional education: A systematic review. Adv Exp Med Biol 1205:149–170.

Pratt RL. 2009. Are we throwing histology out with the microscope? A look at histology from the physician's perspective. Anat Sci Educ 2:205–209.

Proserpio L, Gioia DA. 2007. Teaching the virtual generation. Acad Manag Lear Educ 6:69–80.

Rajendran PR. 2001. The Internet: Ushering in a new era in of medicine. JAMA 285:804.

Ruiz JG, Mintzer MJ, Leipzig RM. 2006. The impact of e-learning in medical education. Acad Med 81:207–212.

Rujano-Balza MA. 2021. Histology classifier app: Remote laboratory sessions using artificial neural networks. Med Sci Educ 31:305–307.

Rusatira JC, Tomaszewski B, Dusabejambo V, Ndayiragije V, Gonsalves S, Sawant A, Mumararungu A, Gasana G, Amendezo E, Haake A, Mutesa L. 2016. Enabling access to medical and health education in Rwanda using mobile technology: Needs assessment for the development of mobile medical educator apps. JMIR Med Educ 2:e7.

Sabbour SM, Dewedar SA, Kandil SK. 2012. Language barriers in medical education and attitudes towards Arabization of medicine: Student and staff perspectives. East Mediterr Health J 16:1263–1271.

Saverino D, Marcenaro E, Zarcone D. 2022. Teaching histology and anatomy online during the COVID-19 pandemic. Clin Anat 35:129–134.

Selvig D, Holaday LW, Purkiss J, Hortsch M. 2015. Correlating students' educational background, study habits, and resource usage with learning success in medical histology. Anat Sci Educ 8:1–11.

Sharmin N, Chow AK, Dong AS, Milos NC. 2021. Histoscope: A Web-based microscopy tool for oral histology education. Healthc Informat Res 27:146–152.

Talmon GA. 2019. Generation Z: What's Next? Med Sci Educ 29:S9–S11.

Thintharua P, Dharmasaroja P. 2020. Histology study in undergraduate medical education. Rama Med J 43:34–40.

Thompson AR, Lowrie DJ Jr. 2017. An evaluation of outcomes following the replacement of traditional histology laboratories with self-study modules. Anat Sci Educ 10:276–285.

Tomlinson T. 2010. Beginning Drupal 7. 1st Ed. Berkeley, CA: Apress. 336 p.

Triola MM, Holloway WJ. 2011. Enhanced virtual microscopy for collaborative education. BMC Med Educ 11:4.

UMMS. 2022. University of Michigan Medical School. University of Michigan Histology Website. University of Michigan Medical School. Ann Arbor, MI. URL: http://histology.medicine.umich.edu/ [accessed 25 September 2022].

Vafa S, Chico DE. 2013. A needs assessment for mobile technology use in medical education. Int J Med Educ 4:230–235.

Van Nuland SE, Hall E, Langley NR. 2020. STEM crisis teaching: Curriculum design with e-learning tools. FASEB Bioadv 2:631–637.

Williams CD, Pitchforth EL, O'Callaghan C. 2010. Computers, the Internet and medical education in Africa. Med Educ 44:485–488.

Wong G, Greenhalgh T, Pawson R. 2010. Internet-based medical education: A realist review of what works, for whom and in what circumstances. BMC Med Educ 10:12.

Yen PY, Hollar MR, Griffy H, Lee LM. 2014. Students' expectations of an online histology course: A qualitative study. Med Sci Educ 24:75–82.

Yohannan DG, Oommen AM, Amogh BJ, Raju NK, Suresh RO, Nair SJ. 2022. "Air anatomy" - Teaching complex spatial anatomy using simple hand gestures. Anat Sci Educ 15:552–565.

Zaidi NB, Hwang C, Scott S, Stallard S, Purkiss J, Hortsch M. 2017. Climbing Bloom's taxonomy pyramid: Lessons from a graduate histology course. Anat Sci Educ 10:456–464.

FIGURE LEGENDS:

Figure 1. The home page of the Michigan Histology website (UMMS, 2022) is the entry point to three different histology courses/sequences that are taught at the UM, the medical and dental histology sequences and the undergraduate/graduate CDB 450/550 Looking Glass course. Each course/sequence has its individual subset of topics and order in which these topics are taught. The home page also has links to an introduction about digital microscopy, to a short summary about histological stains, and to two lists of virtual light micrograph slides and electron micrographs, respectively, that are available on the Michigan Histology website

Figure 2. Monthly session and user numbers of the Michigan Histology website as defined by Google Analytics (Google, Mountain View, CA; Ledford et al., 2011). The number of monthly sessions is represented by the blue line and the number of users by the orange line. The figure depicts quantitative data from September 2016 to June 2022. The grey-shaded area indicates the time period of the COVID-19 pandemic that affected histology teaching worldwide (March 2020 to December 2022).

TABLE 1 Freely accessible histology Internet websites featuring virtual microscopy slides.

Name of the Website (Responsible individuals and institutions/ organizations)	URL of the Website	Features of the Website
Brain Maps (Dr. W.M. Usrey and BrainMaps.org consortium, University of California Davis, CA, USA)	http://brain-maps.org	Virtual central nervous system (CNS) images from a wide variety of species including human specimens
Cell Image Library (The American Association for Cell Biology, Bethesda, MD, USA)	http://www.cellimagelibrary.org/home	Variety of light microscope and electron microscope (EM) digital and virtual images, including animations and movies. Wide range of imaging technologies, cell types, and organisms
Histologic (Dr. P.G. Anderson, University of Alabama School of Medicine, Birmingham, AL, USA)	https://peir.path.uab.edu/wiki/Histologic	Virtual histology slides with some diagrams and labeled digital images, and laboratory manual.
Histology @Yale (Dr. P. Takizawa, Yale University, New Haven, CT, USA)	http://medcell.org/histology/histology.php	Virtual histology slides and digital images (with optional annotation), EMs, laboratory manual, quiz questions, and labeled digital pathology images.
Histology Guide (Drs. T.C. Brelje and R.L. Sorensen, University of Minnesota, Minneapolis, MN, USA)	https://histologyguide.com	Virtual histology slides, EMs (with optional color coding and labels), laboratory manual, and quiz questions
Histology Lab Manual (Dr. P. Spitalnik, Columbia University, New York, NY, USA)	https://histologylab.ctl.columbia.edu	Virtual histology slides, digital images, EMs, laboratory manual, and quiz questions
HistoViewer - Virtual Microscopy for Cell Biology and Histology (Aarhus University, Aarhus, Denmark)	https://histoviewer.biomed.au.dk	Virtual light microscopy slides including a few immune- and histochemistry-stained slides
Indiana University School of Medicine Virtual Microscopy (Dr. M. Braun, Indiana University, Indianapolis, IN, USA)	https://vmicro.iusm.iu.edu	Description of histological structures and organs, virtual histology and pathology slides, EM images, digital images and diagrams, quiz questions
Michigan Histology and Virtual Microscopy Learning Resources (Dr. M. Hortsch, University of Michigan, Ann Arbor, MI, USA)	https://histology.sites.uofmhosting.net	Virtual histology slides, digital images, labeled EMs, laboratory manual, and quiz questions
Medical Histology and Virtual Microscopy Resources (Dr. M. Velkey, Duke University Medical School, Durham, NC, USA)	https://histology.oit.duke.edu	Virtual histology slides and pathology correlates, laboratory manual, unknown virtual slides with identifying answers
Nanotomy: Large-scale electron microscopy datasets (Dr. B. Giepmans, University of Groningen, Groningen, The Netherlands)	http://www.nanotomy.org	Virtual and regular histology and pathology EM images including scalable 3D serial sections. The images are derived from publications and therefore do not present a comprehensive image library

University of Colorado Virtual Histology Lab (Dr. L. Lee, University of Colorado School of Medicine, Aurora, CO, USA)	http://leeshistology.com	Virtual histology slides, quiz access requires an account.
Virtual Histology (Dr. B.R. Espiritu, Loyola University, Chicago, IL, USA)	http://zoomify.lumc.edu	Virtual histology slides, and EMs
Virtual Microscopy (Dr. K. Pinder, The University of British Columbia, Vancouver, BC, Canada)	https://cps.med.ubc.ca/virtual-histology/	Virtual histology slides from various organs and organ systems
Virtuelle Mikroskopie (Drs. R. Bock, I. Lang, J. Schmitt, Universität des Saarlandes, Homburg, Germany)	https://mikroskopie-uds.de	In German, virtual histology slides from several German, Austrian, and Swiss universities

This list of open histology websites only reflects websites that were functional at the time this manuscript was written. Only websites with scalable virtual images (light microscopy and/or EM) that are freely accessible without registration, password, or additional software downloads were included.

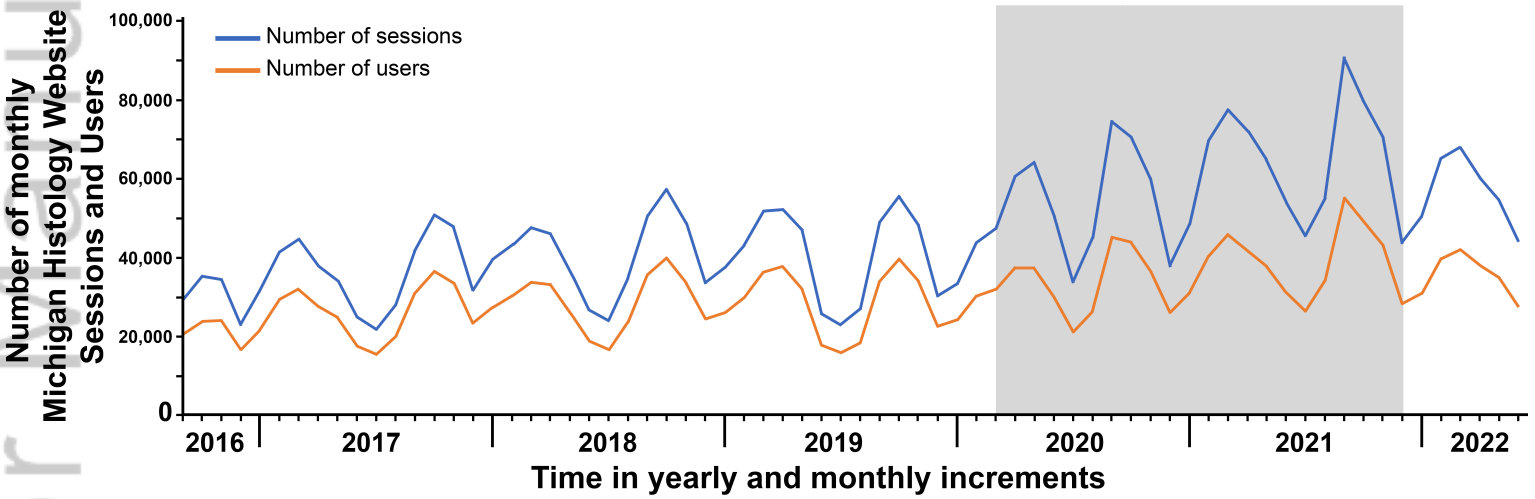
Histology at the University of Michigan

Dear Michigan Histology Website Users,

The conversion of the Michigan Histology website to a Flash-independent viewer has now been completed and you should be able to use any Internet browser to open and view the virtual slides. Users will see only one link for each virtual slide, no longer two (Webscope and Imagescope). All sample and practice question pictures have been converted to still images. The new slide viewer will also work on computer tablets and smartphones. Please let us know about any problems with the new viewer and the revised pages, specifically missing or incorrect links.

Special thanks for their great work goes to the University of Michigan HITS teams as they did most of the transformation work. Specially I would like to mention Naveen Jain, Michael Blake, Brian Simko, Tara Manwaring, and Dima Tawakkol.

The Department of Cell & Developmental Biology at the University of Michigan Medical School provides this digital microscopy resource for the study of cells, tissues and organs. A full list of virtual slides and a full list of virtual EM micrographs are also available.



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