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Using Dynamic Virtual Microscopy to Train Pathology Residents During the Pandemic: Perspectives on Pathology Education in the Age of COVID-19

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Abstract
The COVID-19 pandemic has forced educational programs, including pathology residency, to move to a physically distanced learning environment. Tandem microscopic review (also known as "double-scoping") of pathology slides is a traditional cornerstone of pathology education. However, this requires the use of a double- or multi-headed optical light microscope which is unfortunately not amenable to physical distancing. The loss of double-scoping has forced educational innovation in order to continue teaching microscopy. Digital pathology options such as whole slide imaging could be considered; however, financial constraints felt by many departments often render this option cost-prohibitive. Alternatively, a shift toward teaching via dynamic virtual microscopy offers a readily available, physically distanced, and cost-conscious alternative for pathology education. Required elements include a standard light microscope, a mounted digital camera, computers, and videoconferencing software to share a slide image with the learner(s). Through survey data, we show immediate benefits include maintaining the essence of the traditional light microscope teaching experience, and additional gains were discovered such as the ability for educators and learners to annotate images in real time, among others. Existing technology may not be initially optimized for a dynamic virtual experience, resulting in lag time with image movement, problems focusing, image quality issues, and a narrower field of view; however, these technological barriers can be overcome through hardware and software optimization. Herein, we share the experience of establishing a dynamic virtual microscopy educational system in response to the COVID-19 pandemic, utilizing readily available technology in the pathology department of a major academic medical center.

Keywords
COVID-19, digital pathology, graduate medical education, pathology education, resident education, telepathology, video microscopy, virtual microscopy

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Introduction

The COVID-19 pandemic has forced educational programs, including pathology residency, to move to a physically distanced learning environment. Tandem microscopic review, also known as "double-scoping," of pathology slides is a traditional cornerstone of pathology education. However, many academic medical centers have disallowed this practice during the pandemic because double-scoping inherently requires a

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physical proximity of 2 to 4 feet, which does not meet the common physical distancing recommendation of at least 6 feet of separation between individuals. The loss of double-scoping has forced educational innovation in order to continue teaching microscopy to pathology trainees during the COVID-19 pandemic, with digital pathology options emerging as the most logical substitute available to reconstruct the double-scoping experience in a physically distant manner.

In recent years, the field of pathology has advanced multiple digital pathology systems. Since first used in the late 1960s, various forms of digital pathology have been used for clinical and educational purposes, with 12 distinct digital pathology systems described in the literature.[1,2] Digital pathology systems are currently used to transmit virtual images to distant or remote locations for consultation or frozen section diagnosis,[3-8] and a selective review of the literature has shown a consistent trend of concordance between various forms of digital pathology and conventional light microscopy.[9]

Whole slide imaging (WSI) has emerged as the digital pathology platform of choice for teaching in recent years. Whole slide imaging has utility in both undergraduate and graduate medical education,[10-13] primarily by leveraging stored teaching libraries, study sets, and individual cases to enhance didactic teaching, to monitor acquisition of new skills (eg, stain interpretation), and to assess competency through slide examination/testing.[12] Few if any studies have evaluated the use of this technology as an educational tool capable of replacing double-scoping, as only a few institutions have pursued WSI for primary diagnosis as part of their daily workflow.[14] In part, this may be due to the considerable upfront costs associated with implementing WSI technology and its associated storage requirements. Financial constraints facing many pathology departments often render WSI cost-prohibitive.

Alternatively, a shift toward dynamic virtual microscopy (DVM) offers a readily available, physically distanced, and cost-conscious alternative for pathology education. Definitions for "telepathology," "video microscopy," "virtual microscopy," and "digital pathology" often overlap in the literature; however in this study, a "dynamic virtual microscopy" platform is defined as one light microscope with a mounted digital camera for the educator, digital camera, and videoconferencing software to stream a slide image to the learner(s), and one computer per participant.

The term "virtual microscopy" is intentionally used in this study to emphasize the learner's perspective of slide viewing during this teaching activity, while admittedly from the educator's perspective the term "video microscopy" would more accurately represent their use of a live video system to project the image to the learner. The term "dynamic" is intended to reflect the real-time nature of the teaching interaction.

Already utilized for communication between distant users,[1] studies examining the use of a DVM platform for pathology trainee education are lacking. Herein, we share the experience of establishing a DVM educational platform utilizing readily available technology in the pathology department of a major academic medical center in response to the COVID-19 pandemic.

Materials and Methods

A cross-sectional study of pathology faculty and trainees was conducted at a major academic teaching hospital to assess current perspectives on utilizing a DVM platform to teach microscopy during the COVID-19 pandemic. At the onset of statewide emergency shutdown orders, all hematopathology, cytopathology, and surgical pathology faculty and trainees were asked to use DVM for all clinical and educational purposes involving more than one person. This included all large and small group teaching activities, as well as all consensus conferences and tumor boards. At the time of the study, DVM had been in use for approximately 6 months and the department consisted of 46 faculty, 5 pathology fellows, 11 Anatomic and Clinical Pathology residents, 1 Anatomic Pathology only resident, and 3 post-sophomore student fellows. Of note, all faculty utilized DVM for the entire 6-month period; however, the trainees had variable exposure to DVM depending upon their rotation schedule and/or level of tumor board involvement. At the present time, DVM continues as the primary form of microscopy teaching at our institution. Double-scoping is not currently allowed due to physical distancing requirements.

Dynamic Virtual Microscopy Platform

The primary purpose of instituting a DVM platform at our institution is to maintain physical distancing during the COVID-19 pandemic while continuing to educate pathology learners and share microscopic findings with colleagues. In this study, a "dynamic virtual microscopy platform" is defined as one light microscope with a mounted digital camera for the educator, digital camera, and videoconferencing software to stream a slide image to the learner(s), and one computer per participant. Before onset of the pandemic, all necessary hardware and software was already available for use, although an individual user's hardware/software combination, installation status, and prior experience with their setup was highly variable.

Prior to the pandemic, viewing microscopy almost exclusively relied on learners or colleagues utilizing double- or multi-headed microscopes. Use of mounted digital cameras was primarily limited to taking static images of slides for journal articles, presentations, or tumor boards. However, some faculty used a mounted digital camera and associated software to project slide images to a single monitor for occasional consensus/teaching conferences, tumor boards, or within their office when the number of learners in the room exceeded the number of available microscope heads. In these instances, maintaining adequate physical distancing was not yet a relevant consideration.

Use of videoconferencing software in the workplace prior to the pandemic was also limited to a few faculty members who occasionally utilized videoconferencing software to collaborate with external colleagues. There was no routine use of videoconferencing software for educational purposes or conference presentations prior to implementing DVM.

Educational Workflow

When utilizing DVM, faculty and trainees are physically present on campus but each individual is in a separate, preassigned workspace that meets institutional and departmental guidance for adequate physical distancing. Glass slides are processed and prepared by the histology department and distributed to the appropriate subspecialty mailbox. The assigned trainee retrieves these slides and previews in a manner unchanged from the prepandemic state, including making relevant annotations on the glass slides and writing reports in the electronic medical record (EMR). However, prior to the scheduled teaching interaction, the trainee delivers all glass slides to the faculty's mailbox before returning to their designated workspace to begin the teaching interaction of reviewing slides/cases together ("sign-out"). Both the faculty member and trainee log on to a videoconferencing session to review microscopic findings in tandem, with the faculty member driving a light microscope and simultaneously projecting the slide image to the learner's computer monitor through the mounted digital camera, camera software, and videoconferencing software. Faculty and trainees most commonly use built-in computer audio with attached headsets to communicate with one another during the interaction, or occasionally use telephones to work around poor connectivity or audio feedback issues. If multiple learners are present, each learner joins the videoconferencing session using their own computer from their own designated workspace.

Of note, during sign-out, the faculty user has the ability to switch the view on their monitor from the virtual image to the EMR. This creates an opportunity to deliver immediate feedback to the learner as they can directly observe the pathologist editing the pathology report in real time and/or turning to the medical record for additionally needed clinical information. Alternatively, faculty and trainees who happen to have 2 monitors per participant are able to view the EMR and virtual image simultaneously by utilizing 2 concurrent videoconferencing sessions, one monitor and videoconference to display the virtual image, and the second monitor and videoconference to display the EMR. Depending on the videoconferencing software used, this may require the use of 2 unique software accounts or 2 distinct videoconferencing platforms simultaneously.

Tumor Board/Conference Workflow

Tumor board and other educational conferences within and outside of the pathology department were also reconfigured to meet the physical distancing requirements of the COVID-19 pandemic by utilizing DVM. For pathologists, the workflow to prepare for these conferences is relatively unchanged from the prepandemic state and continues to include case review and quality assurance functions as appropriate to the situation. However, similar to DVM in the educational setting, presentation of the microscopy is performed by the pathologist driving a light microscope and projecting the slide image to the conference participants through the mounted digital camera, camera software, and videoconferencing software. In contrast to the education workflow, however, conference participants join the videoconference session from on- and off-campus locations via a variety of audiovisual combinations, including smartphones with or without images, telephone only, and various computer/laptop/tablet setups.

Of note, tumor board conference participants also have the ability for the pathologist to share the EMR via videoconferencing software. Visually displaying the associated pathology and ancillary testing has improved the transfer of information to clinicians who prefer reading details, such as specific molecular alterations identified, rather than relying on the short verbal summary traditionally made by pathologists when presenting a case.

Participants and Recruitment

Potential survey participants included most pathology faculty and all trainees (post-sophomore fellows, residents, and fellows). Participants were recruited via faculty and trainee email list-serves already in use at the time of the study. Only current faculty and trainees were included in the study and participants were limited to those who had used or were asked to use DVM for the purposes of trainee education. Potential participants totaled 66 faculty and trainees in the following categories: 46 hematopathology, surgical pathology, or cytopathology faculty; 5 pathology fellows (2 surgical pathology, 1 hematopathology, 1 cytopathology, and 1 molecular fellow); 11 anatomic and clinical pathology residents (4 at post-graduate year (PGY)-1, 4 at PGY-2, 1 at PGY-3, 2 at PGY-4); 1 anatomic pathology only resident (PGY-3); and 3 post-sophomore student fellows. All others were excluded from the study.

Data Collection and Analysis

Perspectives of faculty and trainees were assessed via survey 6 months after implementation of DVM within the pathology department of a major academic medical center. A survey with 5-point Likert-type items (see Supplemental File 1) was sent out to potential survey participants regarding the use of DVM ("virtual platform") compared to traditional optical microscopy ("double-scoping") for trainee education ("sign-out") and tumor board/conference participation. Twenty questions focused on experiences with lag time, white balance, resolution, field-of-view, image focus, the use of pointer arrows on the microscope and the computer, the ability to annotate, ease of use, convenience, optimization, and trainee education. Responses were analyzed as individual ratings and statistical means and standard deviations were calculated.

Results

An explanatory email containing a survey hyperlink was sent to the 66 faculty and trainees defined above. There was a 48% response rate ($n = 32$). Four responses were excluded from data analysis, including 3 respondents who did not meet inclusion

Table 1. Study Population, Including Early Learners (Student Fellows, PGY-1 and PGY-2 Residents), Late Learners (PGY-3 and Above Residents, Fellows), and Faculty.

Group name, n (%)			
Early learner	Late learner	Faculty	All
9 (32%)	6 (21%)	13 (47%)	28 (100)

Note: PGY, Post-Graduate Year

Table 2. Perceived Disruptions of Using the Virtual Platform Compared to Optical Platform.*

Question	Early learner, mean (SD)	Late learner, mean (SD)	Faculty, mean (SD)	All, mean (SD)
Lag time	3.1 (0.9)	3.8 (1.0)	3.8 (1.2)	3.6 (1.0)
White balance	3.1 (1.1)	4.0 (1.1)	3.1 (1.8)	3.3 (1.4)
Pointer arrow	2.1 (1.4)	2.5 (0.8)	3.4 (1.3)	2.8 (1.3)
Pointer cursor	1.7 (0.9)	2.2 (1.0)	2.2 (1.4)	2.0 (1.1)

*Based on 5-point Likert-type items: 1 = no disruptions, 2 = few disruptions, 3 = some disruptions, 4 = many disruptions, and 5 = significant disruptions.

Table 3. Perceived Image Focus Between Virtual and Optical Platforms.*

Question	Early learner, mean (SD)	Late learner, mean (SD)	Faculty, mean (SD)	All, mean (SD)
Are images in focus together?	3.1 (1.4)	2.7 (1.2)	3.3 (1.3)	3.1 (1.2)

*Based on 5-point Likert-type items: 1 = always in focus together, 2 = more often in focus together, 3 = sometimes in focus together, 4 = more often not in focus together, and 5 = never in focus together.

criteria and 1 who did not complete the survey. Twenty-eight respondents met all inclusion criteria and were included in the analysis. Respondents were subclassified according to their current position in the pathology department: 32% (n = 9) identified as "early learners" (post-sophomore fellows, PGY-1 residents, or PGY-2 residents); 21% (n = 6) as "late learners" (PGY-3 or above residents and fellows); and 47% (n = 13) as faculty (Table 1).

Four survey questions asked about perceived disruption to workflow associated with the virtual platform when compared with the traditional optical microscopy platform. Response choices were based on a 5-point scale ("no disruptions" = 1, "few disruptions" = 2, "some disruptions" = 3, "many disruptions" = 4, and "significant disruptions" = 5). Results regarding perceived disruption of workflow are summarized in Table 2.

When asked about image lag time and white balance issues, all groups on average perceived some to many disruptions, with many disruptions being reported by the late learner group (mean = 4.0, SD = 1.1). The use of the pointer arrow on the optical scope and pointer cursor of the computer was perceived to cause few to some disruptions among all groups on average, with the faculty group perceiving some to many disruptions while using the pointer on the microscope (mean = 3.4, SD = 1.3), and the early learner group perceiving no to a few disruptions while using the pointer cursor of the computer (mean = 1.7, SD = 0.9).

One survey question asked about the focus of the virtual image on the computer screen compared to the optical microscope (Table 3), based on a 5-point scale from 1 being "always in focus together" to 5 being "never in focus together." On average, the groups found the images to be sometimes in focus together (mean = 3.1, SD = 1.2).

The remaining 15 survey questions are summarized in Figure 1 and address questions about the field-of-view, the ability to annotate, the ease of use for sign-out and tumor board, the convenience for sign-out and tumor board, the perceived optimization of the virtual platform, whether the virtual microscopy platform is adequate and ideal for trainee education, and which platform the respondent would prefer for trainee education and tumor board. Questions were based on a 5-point scale ranging from −2 (heavily favor the virtual platform/completely agree) to +2 (heavily favor the optical platform/completely disagree), with 0 being neutral. Statistical significance was found among the early learner group who favored the traditional optical microscopy platform for both image resolution (mean = 1.4, SD = 0.5) and field-of-view (mean = 1.6, SD = 0.7). Statistical significance was also found among the late learner group who favored the traditional optical microscopy platform for image resolution (mean = 1.3, SD = 0.5) and field-of-view (mean = 1.8, SD = 0.4), but also favored the virtual platform if it were to be completely optimized due to its convenience for tumor board (mean = −1.6, SD = 0.5), and somewhat disagreed to completely disagreed with the statement "in its current state, the virtual microscopy platform is ideal for trainee education" (mean = 1.8, SD = 0.4). Statistical significance was also found between the 3 groups as a whole, all favoring the traditional optical microscopy platform for both image resolution (mean = 1.4, SD = 0.6) and field-of-view (mean = 1.6, SD = 0.7). No statistical significance was found among the faculty group for any of the questions.

Discussion

Digital pathology is considered a valuable tool for medical education. However, current focus is predominately on the use of WSI as an assessment or study tool for pathology trainees,[12] with little attention to its use as a pathology teaching tool during daily slide review and sign-out of active cases pending a primary diagnosis. Although recent studies have assessed the utility and diagnostic accuracy of virtual microscopy systems when compared with optical microscopy, the educational value of virtual microscopy has not yet been assessed.[8]

As demonstrated by this survey, teaching microscopy via DVM has both advantages and disadvantages when compared with teaching via traditional optical microscopy. The most

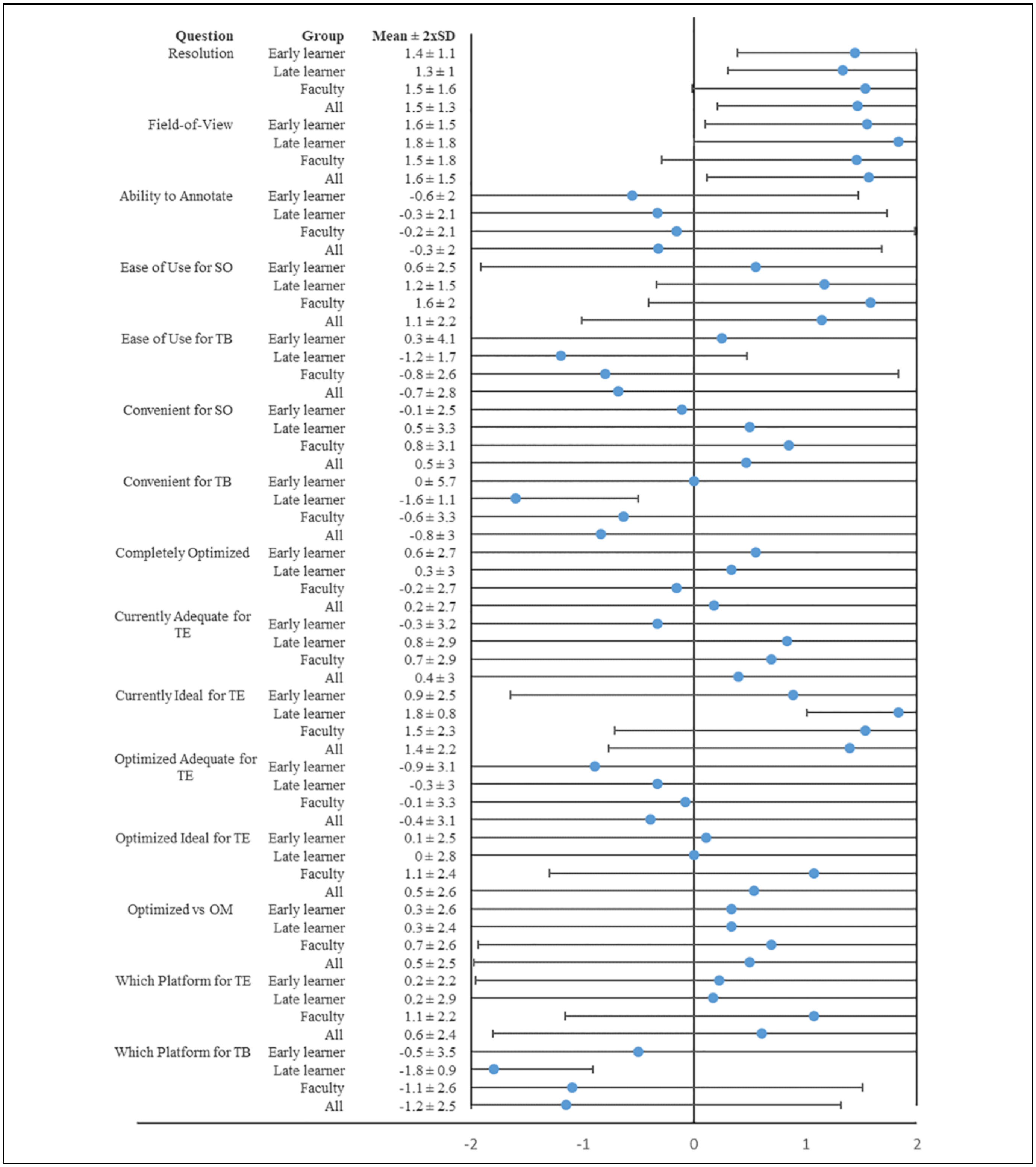

Figure 1. Faculty and trainee platform preference. Participants were asked about various aspects of the virtual and optical platforms, and responses were based on 5-point Likert-type items. Answers strongly favoring the virtual platform were assigned values of −2, answers somewhat favoring the virtual platform −1, neutral answers 0, answers somewhat favoring the optical platform +1, and answers strongly favoring the optical platform +2. Data shown for each survey question as mean ± 2 × SD for each group and the groups as a whole. OM indicates optical microscopy platform; SO, sign-out; TB, tumor board; TE, trainee education.

notable advantage of the virtual platform is the ability to maintain adequate physical distancing while also continuing to teach trainees and share microscopic findings at tumor board/conferences, which is of utmost importance during the COVID-19 pandemic. However, an additional advantage is that both the educator and the learner can annotate a virtual image in real time using the videoconferencing software and can accurately place marks at a microscopic magnification only possible digitally. When compared with the tradition of trainees annotating with a marking pen on a glass slide, which occurs prior to the educational interaction and with a relatively blunt marking tool, annotating on the virtual image is timelier and more detailed. For example, the educator could create a spontaneous, quiz-style interaction based on an image viewed at 40× where the learner must both describe the salient nuclear features of papillary thyroid carcinoma while simultaneously using the annotation tool to circle examples of each feature on the virtual image to further display that their "book knowledge" translates to their "microscopic eye." Additionally, the annotation tool allows the learner to point to a microscopic finding themselves, a feature traditionally limited to only the educator whose microscope has a built-in pointer tool.

Although not specifically asked in the survey, another benefit of DVM anecdotally observed is increased attendance at conferences, such pathology consensus conferences, interesting case conferences, unknown slide conferences, and didactic teaching conferences. Increased attendance is assumed to be attributable to the fact that participants can easily join from a variety of locations without a commute, such as their home, office, or car, but also because participants are not limited by health or accessibility issues. Furthermore, DVM can accommodate larger learner groups, such as medical student laboratories, because its use is not limited by the number of heads at a microscope.

Dynamic virtual microscopy is also notable for its relative convenience. Whether facilitating clinicopathologic correlations with interested clinicians or answering questions from a trainee during the workday, DVM opens up new and convenient avenues to share the microscopic findings of a case without the barrier of physically colocating to a room with a microscope. Many of the skills and interactions used for daily sign-out with DVM can be carried over to interactions aimed at clinicopathologic correlation, including reviewing microscopic findings or synchronously viewing pathology reports or ancillary studies within the EMR. Additionally, if pathology trainees have a workspace setup for DVM (ie, their designated workspace includes a microscope with mounted camera), it would allow them the opportunity to take primary responsibility for showing cases to clinicians or pathologist consultants (with or without direct observation by their pathologist attending), which could be established as a key mechanism to promote graduated responsibility within the resident and fellow training program. Furthermore, allowing a trainee the opportunity to initiate a virtual microscopy encounter allows for a more 2-way form of communication between the trainee and pathologist. This is of potential benefit as it encourages asking questions about a case or building specific skills, such as stain interpretation, in real time.

Unfortunately, DVM also comes with significant disadvantages and difficulties that were highlighted by the survey data. Image lag time, distortion of white balance (especially while switching objectives), image focus and resolution, and discordant fields-of-view are considerable dissatisfiers for both faculty and trainees when using DVM. Of note, a variety of hardware and software combinations were used by the participants in this study, not a single "platform," and unfortunately the details of each setup were not captured within the survey. Anecdotally, some faculty are reported to have superior combinations of hardware and/or software that greatly improve the user experience, which highlights an interesting potential area for further study.

Consideration of the user interface is key to successful implementation of DVM. As discussed by Luo and Hassell,[15] the user interface is critical for successful adoption of WSI in residency education, as "pathology residents who have mastered the utility of the microscope and glass slide recognize how readily tremendous amounts of information are conveyed efficiently through that medium." The same statement can be applied to the use of DVM. Improvements in digital cameras, computer monitors, internet bandwidth, adapters, and video cards are just a few of the enhancements to consider as some or all of these components may not be capable of transmitting high-quality dynamic digital images. Furthermore, ad hoc combinations of technology or attempting to use hardware and software in ways in which they were not specifically designed, may inadvertently result in lag time with image movement, problems focusing, image quality issues, and a narrower field-of-view.

The most expensive hardware enhancements involved with DVM are likely to be the camera and computer monitors. High-quality digital cameras, including those cameras not specifically meant for microscopes, and Quad High Definition (QHD) or 4K computer monitors are the most likely to improve image quality. One faculty member fully optimized their digital platform by purchasing a high-quality digital camera and multiple 4K computer monitors, and anecdotal reports are overwhelmingly positive with image quality nearly identical to that of an optical light microscope. Upgrades to a high-speed internet connection and a high-definition videoconferencing service optimized for dynamic images may further enhance the quality of experience but may also add significant cost.

Although optimization of a virtual system is ideal, lack of optimization does not necessarily preclude implementation of DVM. As seen in this department, multiple combinations of hardware and software were utilized in DVM teaching interactions. Although some combinations do not provide the most optimal user interface, the ability to discuss relevant teaching points and the platform's other advantages are still available. Even a basic setup made with any microscope mounted camera that projects to a computer screen, videoconferencing software with a "share screen" feature, and a LAN or Wi-Fi internet connection can be made into a virtual platform and allow microscopy education to continue during the pandemic. Although technological optimization will make the image quality of the virtual platform closer to that of the optical platform, it may not be entirely necessary nor worth the cost depending on an individual institution's needs.

In addition to the technological perspective, the altered social aspects of DVM must be considered. In the traditional sign-out experience with an optical light microscope, the physical proximity of the educator and learner allows for more transparency of visual cues such as a puzzled look from a trainee or fidgeting in the chair to signal discomfort or lack of focus with a particular topic. The use of webcams may aid DVM participants in this regard. Many videoconferencing software platforms have the ability to share screen images while simultaneously projecting the webcam images of each attendee; however, social cues may be more easily missed using DVM even with the addition of a webcam. Although not a replacement for physically proximity, webcams can enhance the virtual sign-out experience.

There are multiple limitations to this study. First, many of the survey respondents in the early learner group have only experienced the virtual platform because their training began amid the COVID-19 pandemic. Therefore, their experience with in-person double-scoping is limited and may have affected their ability to compare these 2 teaching platforms. Second, this survey did not ask faculty for demographic information such as age, length of practice, or length of time in the department, nor did it ask faculty or fellows to identify the subspecialty in which they work. Therefore, additional analysis utilizing these factors is not currently possible, although in hindsight it would have been ideal to further stratify the survey results to determine whether certain subspecialties more significantly favor one of the 2 platforms. Third, many limitations arose from utilizing only readily available technology in our pathology department. Hardware variations were numerous, including use of various brands of microscopes (ie, Olympus, Leica), objectives, digital cameras, and monitors. Also, a mix of laptop and desktop computers were used by trainees. Software variations were also present, including camera related software and videoconferencing software (ie, WebEx, Microsoft Teams). These differences resulted in significant variation between DVM experiences which likely influenced the survey results.

Finally, it should also be noted that adjustments to new technology take time. Individual users may adapt quickly or slowly to the new method, and each may require varying amounts of technological support to improve their operational skill with the new system. Implementation of DVM at our institution was done out of necessity secondary to the physical distancing requirements caused by the COVID-19 pandemic. Needless to say, this time of urgency, uncertainty, and anxiety in our lives likely held significant influence over each participant's willingness or interest to adopt to new technology, which is a significant limitation not to be dismissed in this study.

Conclusion

In summary, although many academic pathology programs have access to the hardware and software required to begin teaching via a DVM platform, the existing technology may not be fully optimized, resulting in lag time with image movement, problems focusing, image quality issues, and a narrower field-of-view. However, the necessity to comply with physical distancing requirements during the COVID-19 pandemic may outweigh these drawbacks. Technological barriers may be overcome through hardware and software optimization; however, the cost of these upgrades in combination with the (un)willingness of individual users to adopt to new technology could be significant hurdles to implementing a successful DVM educational platform. It is our hope that sharing our experience converting to DVM for all educational purposes may provide some guidance to other pathology educators and learners who are struggling with how to continue pathology education during the COVID-19 pandemic.

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Supplemental Material

Supplemental material for this article is available online.

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