Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Annals of Diagnostic Pathology 49 (2020) 151612

Contents lists available at ScienceDirect

Annals of Diagnostic Pathology

journal homepage: www.elsevier.com/locate/anndiagpath

Original Contribution

Remote pathology education during the COVID-19 era: Crisis converted to opportunity

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ARTICLE INFO

Keywords:
Digital pathology
Undergraduate education
Distance learning
COVID-19
Kern's 6-step approach
Zoom

ABSTRACT

Context: The COVID-19 pandemic led to shutting of education faculties, including clinical clerkships for medical students.
Objective: To review a selective for a course in diagnostic pathology geared toward undergraduate medical students, including its design, technical implementation, instructor and student evaluations, and suggestions for options for further adjusting and optimizing the selective.
Design: Whole slide images (WSI) were anonymized and students were given remote access to university computers, which were prepared with two freely available WSI viewers. Each topic was taught in a four-part module: Self-assigned reading, lecture via Zoom, quiz based on digital slide sets, and a frontal review of the slides via Zoom. Fifty-nine students participated in the selective. Following the course, students completed an anonymous questionnaire.
Results: Of the 59 participants, 42% (n = 25) responded. None of the respondents had any previous instruction in diagnostic pathology. Overall, the course was rated very favorably: 68% (n = 17) gave at least 3 points on a 4-point scale on questions relating to course interest, improvement in understanding of the covered diseases, and how strongly they would recommend a student take this course if given an option. The most significant disadvantage of the class, as reported by 80% (n = 20) were technical challenges in accessing the slides.
Conclusion: We believe the course was a success and can be a model for future virtual pathology electives. Great effort should be done to provide technical support to the students. The selective demonstrated value for students and provided much-needed exposure to diagnostic pathology in clinical practice.

1. Introduction

On 11 March 2020, the World Health Organization publicly "made the assessment that COVID-19 can be characterized as a pandemic" [1]. Four days later, the State of Israel announced a shutting of all educational facilities [2]. This decision precluded medical students both from in-person lectures and being present in the hospital wards. The Medical School of International Health (MSIH) of Ben Gurion University of the Negev (BGU) in Israel is a four-year international MD program modeled on the United States educational curriculum. As such, students in their first two years (termed M1 and M2) are primarily focused on lecture-based preclinical studies, whereas upperclassmen (M3 and M4) normally participate in one-month electives and two-week selectives in the clinical setting, such as hospital wards and outpatient clinics.

Guidelines issued by the State required MSIH to implement a variety of alternate educational solutions in order to prepare the students to practice medicine and to maintain their academic timeline for graduation and advancement to fourth-year. While various distance learning solutions have been adapted for pre-clinical instruction, for which it is more suitable, the same format is not as well tailored to M3 and M4 clinical experiences. Nonetheless, distance learning was used for various courses in these academic years, including radiology and psychiatry.

One of the implemented solutions at MSIH was to create a new Diagnostic Pathology Selective, in which distance learning was used to provide upperclassmen with a unique educational opportunity. Herein, we describe the course, including our technical implementation, benefits and limitations, and student satisfaction. Before this course was designed, students at MSIH were given a dedicated introduction to pathology course in their first year which covered general pathology, followed by integration of systems pathology within the later courses. However, with the exception of the very occasional tumor boards

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https://doi.org/10.1016/j.anndiagpath.2020.151612

Available online 29 August 2020

attended by some of the students (see Results, Section 3), we feel there is traditionally inadequate exposure to surgical pathology in clinical practice and decision making.

A number of previously published papers provide background and useful insights for developing a distance-based learning curriculum. While lessons can be learned from university systems in the United States and Canada that offer a distributed curriculum, [3,4] this solution is quite costly and addresses a similar albeit different issue, namely that large groups of medical students are situated in rural areas while the nearest major diagnostic pathology center with its educators is in an urban area. Further, an excellent article by Hamilton et al. [5] extols the virtues of incorporating virtual microscopy for medical education. In the 8 years that have passed since its publication, additional software has been developed for this purpose, which we review here, and importantly incorporate it as a part of a curriculum designed for distance learning. A more recent article [6] provides a brief overview and instructor evaluation of a breadth of these newer resources, including social media; however, it similarly lacks a helpful curriculum outline and retrospective evaluation of resource implementation.

Innumerable web-based slide sharing applications have been developed, too many to be mentioned. The publication [7] of the American Association for Anatomy's Virtual Microscope Database (VMD) opens with the many advantages of using digital microscopy in education from the student, instructor, and institutional perspective. However, in our experience, “centralized” digital slide archives, including the VMD, have many significant limitations. These include difficulties in student registration, slow response time, limitations in slide availability (both in terms of diagnosis and in ancillary tests that could have also been scanned), friendliness of the user interface, compatibility with various devices and operating systems, and ability to save notations (students and instructors). For all of these reasons, at the current time, we recommend that an educational institution with the resources to host its own slide set should do so. In the future, a fast and well-designed centralized slide archive that offers the ability for instructors to upload their own collection could alleviate the value of a local slide set, and could distribute the costs of maintenance via institutional subscriptions, but after extensive exploration and testing, it seems that nothing of the sort yet exists.

We believe that the following paper will be an invaluable guide to pathology educators in the undergraduate setting for two principal reasons: First, the emphasis on distance learning will likely be greater post-COVID-19 than in the past. Described herein are various options for the specific implementation of distance learning in pathology, including our experiences and evaluations of these options. Second, undergraduate medical students frequently are underexposed to diagnostic pathology, and the curriculum discussed in this paper successfully piqued student interest in the field, at least in the short-term.

2. Materials and methods

In order to prepare for the course, the Course Coordinator (BS, corresponding author) prepared a curriculum with accompanying slide sets from surgical biopsies in the Department of Pathology at Soroka University Medical Center. In this section, we first describe with technical implementations of the course following by the academic aspects.

2.1. Technical preparation for the course

Whole slide images (WSI) were prepared using a Pannoramic MIDI automated digital slide scanner (3DHistech, Budapest). The WSI's were anonymized by removing all identifiable information, including the coded biopsy number assigned for internal department tracking purposes. The students were given access to a virtual private network service (VPN), which then enabled remote desktop access to BGU computers. The BGU computers were prepared with two freely available WSI viewers: CaseViewer 2.3 (3DHistech, Budapest) and Aperio ImageScope 12.3.3 (Leica, Illinois). Alternatively, using the VPN, students could map a particular BGU server as a network drive and use any compatible WSI viewer on their computer; this solution was useful for students who had difficulties with remote desktop. These options were selected because they can be implemented on a minimal budget and did not require extensive investment of human resources from the university's computer department. The students are made aware of all three of these options and were asked to provide feedback on their preferred slide viewer (see Supplement 1). The evaluations of CaseViewer and ImageScope are part of an ongoing process at our institution among the faculty involved in the Histology and Pathology curricula, as we were planning on incorporating digital slides into both of these courses just before the pandemic began.

Other than the two options provided by BGU (VPN-restricted remote desktop or mapping the server as a network drive), other options exist for students to access slides. Paid options that are significantly more user-friendly include software suites from various companies (eg Philips Educational Suite with Pathology Tutor or 3DHistech CaseCenter). Alternatively, the OpenSlide platform (Carnegie Mellon University, Pennsylvania) is a free C-library, also available in Python and Java, which can serve slides in a normal webpage over HTML. While this last option would have been considerably more convenient for the students, it would have required greater investment from the computing department, which was not feasible during the emergency transitions being made across the faculty to distance learning.

Preparing anonymized WSI can technically be accomplished in one of two ways. Within the 3DHistech software environment, which is the one employed by BGU, the slide label is stored separately from the biopsy itself and can easily be deleted using Slide Converter 2.3 (3DHistech, Budapest). Further detailed information about the two methods we have used for anonymizing slides, as well as the benefits and limitations of different WSI formats (Mirax, iSyntax, and OME-TIFF) specifically within the context of undergraduate medical education are discussed in Supplement 2 [8].

2.2. Curriculum design

Construction of the pathology selective was based on Kern's 6-step approach to curriculum development [9] (Table 1). Within days of the official announcement precluding medical students from their normal clinical training, the course coordinator (BS, corresponding author) was asked to develop the curriculum, and was given a time frame of approximately 2 weeks before it began. This emergency framework introduced some limitations (see Discussion, Section 4).

Fifty-nine students were enrolled in the selective; of them 25 were M3 and the remaining 34 were M4. Several topics (Table 2) in Diagnostic Pathology were selected for student education. Each topic was taught in a four-part module that consisted of:

1. Self-assigned reading in one of the Robbins textbooks as determined by the Course Coordinator
2. Frontal lecture over the Zoom platform (Zoom Video Communications, Inc., California)
3. Students accessed the digitized slides and record their diagnoses in an online quiz administered on Moodle (Moodle HQ, Australia)
4. Review of the slides from Part 3 conducted over Zoom

For each module, a number of items on a differential diagnosis were developed (Table 3). The students would first be required to independently prepare their understanding of the differential diagnosis, which variably including diagnostic criteria, histological findings, immunostains, molecular pathways, treatment, and prognostic factors. Required and optional reading selections were freely accessible to the students via the BGU Library subscription to Clinical Key (Elsevier, Amsterdam). These included Robbins Basic Pathology, 10th edition

Table 1
Pathology selective curriculum development using Kern's 6-step framework.

Kern's 6-step framework	Pathology selective curriculum
1. Problem identification	-Formal undergraduate education in diagnostic pathology is lacking -The COVID-19 epidemic demands an increased emphasis placed on distance learning for medical students
2. Needs assessment	-Appropriate application of the diagnostic pathology report is a cornerstone of the management and prognostication for several diseases -Better exposure to diagnostic pathology could pique students' interest in pursuing it as a career
3. Goals and objectives	-Introduce surgical pathology to the medical students as an interesting specialty that should be considered for postgraduate training -Reinforce the pathological basis for disease, including mechanisms of diseases and their treatments -Develop an appreciation for "the way a pathologist thinks," such as the approach a biopsy and the understanding of diagnostic criteria, so that ultimately the future clinicians (which are represented by most students) can better understand what a pathologist "means" in his or her report and the significance of commonly described findings
4. Educational strategies	-Selected textbooks and pathology atlases provide students with a core understanding of selected diseases -Live teaching sessions online -Independent interaction with diagnostic digital slides
5. Implementation	-Four-part module described in text of the article, Section 2.2
6. Evaluating the effectiveness of the curriculum	-Quizzes on the content -Post-curriculum survey

Table 2
Topics covered in the Diagnostic Pathology Selective.

Principles of nonneoplastic (inflammatory) and neoplastic (benign, malignant) disorders
Dermatopathology: melanocytic lesions, epithelial lesions, inflammatory dermatoses
Breast pathology
Neoplastic neuropathology
Neoplastic thyroid pathology
Advanced topics in diagnostic pathology: NUT carcinoma, advanced topics in thyroid pathology

Table 3
Select modules with their differential diagnoses.

Inflammatory dermatoses
Erythema multiforme/Steven Johnson/toxic epidermolysis necrosis (TEN) spectrum
Lichen planus
Psoriasis
Pemphigus vulgaris
Bullous pemphigoid
Epithelial neoplastic dermatopathology
Seborrheic keratosis
Epithelial dysplasia (carcinoma in situ, solar keratosis, etc)
Invasive squamous cell carcinoma
Basal cell carcinoma
Fibroepithelial polyp
Breast pathology
Intraductal papilloma
Fibrocystic changes
Radial scar
Usual ductal hyperplasia
Ductal carcinoma in situ
Invasive ductal carcinoma
Lobular carcinoma in situ
Invasive lobular carcinoma
CNS neoplasia
Astrocytoma, diffuse (WHO Grade II) or anaplastic (WHO Grade III)
Glioblastoma, WHO Grade IV
Oligodendroglioma, WHO Grade II
Ependymoma, WHO Grade II
Meningioma, WHO Grade I
Meningioma, atypical (WHO Grade II) or anaplastic (WHO Grade III)
Medulloblastoma, WHO Grade IV
Thyroid neoplasia
Follicular adenoma
Follicular thyroid carcinoma
Papillary thyroid carcinoma
Anaplastic thyroid carcinoma

(Elsevier, 2017), Robbins and Cotran Pathologic Basis of Disease, 9th edition (Elsevier, 2015), and specific chapters in a number of surgical pathology atlases that aid in the appropriate differential diagnoses.

The "frontal" lecture was given over Zoom and was PowerPoint based, lasting 45 min. However, attempts were made to keep this interactive. Each disease was introduced with a skeleton slide with the most important headlines listed (clinical aspects, histological findings, molecular pathology, see Fig. 1), and students were encouraged to tell what information should be completed under the headline, with some success (see Results, Section 3). The Zoom "survey" feature was also used. For students who could not attend the live session, a recording of the lecture was available via the Zoom cloud.

After the lecture, students were given a quiz, which usually consisted of 5 questions based on digital slides. In several modules, the questions were a simply multiple choice of "what is the most likely diagnosis?" In the breast module, students were also asked to interpret receptor stains.

In the final part of each module, each slide was reviewed over Zoom, with focus on the quiz questions but also exploring other important features that would be mentioned in a pathology report. This session was likewise recorded and available for later playback.

During one of the last modules, neuropathology, as part of the course evaluation, pre-test was administered in which students were shown a tumor and asked to classify it as either astrocytic or oligodendroglial. The pre-test was given before the frontal Zoom lecture and was composed of 15 questions, each with a single image taken from one of three neuropathology atlases published by Elsevier/Saunders (Ellison's Neuropathology, 3rd ed.; Prayson's Neuropathology, 2nd ed.; or Yachnis' High Yield Pathology: Neuropathology). As this module was one of the last modules, the students had already reviewed a significant number of slides under instruction and could appreciate concepts of monomorphism vs pleomorphism and hyperchromasia.

The overall module consisted of 8 sessions spanning 2 weeks. The beginning of each live session represented the fourth part of the 4-part module, and then we transitioned into the first part of the next module. The first session was dedicated to developing a general appreciation for important general concepts in inflammatory and neoplastic diseases, and an additional 2 sessions (one at the half-way point and the final session) were dedicated to more advanced topics of interest, using the main curriculum as a starting point (eg NIFTP was discussed in a session after the thyroid neoplasia module).

The course was graded pass-fail based on evidence of serious student participation, which included the quizzes and the live lectures. Following the course, students were asked to complete an anonymous questionnaire (see Table 4).

Informed consent was obtained in accordance with study approval

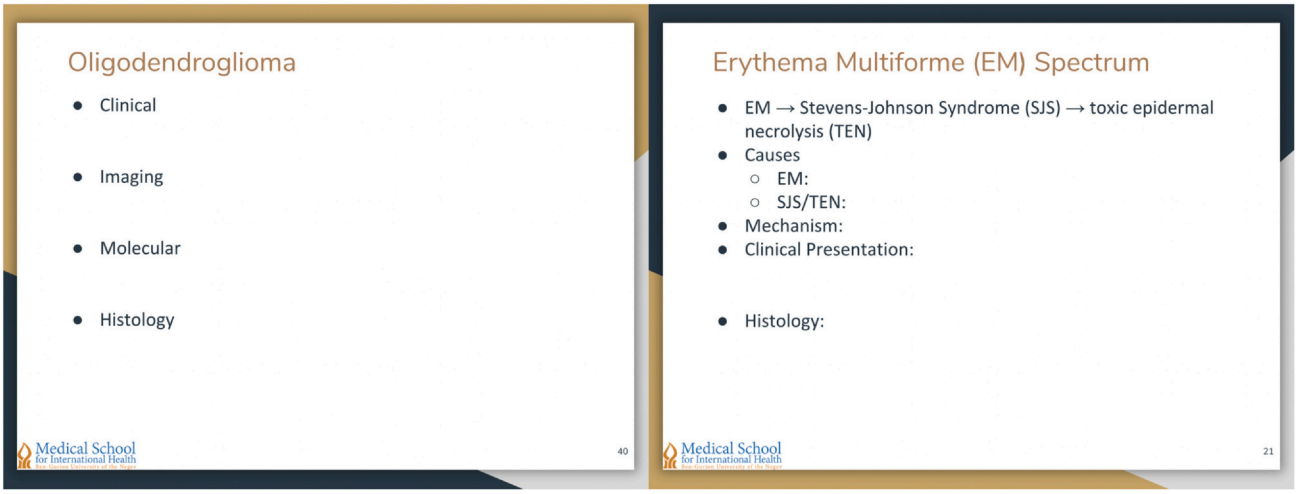

Fig. 1. Sample PowerPoint slides from the lectures on CNS neoplasia (left) and inflammatory dermatoses (right). Special care was taken to encourage the students to participate in the lecture and fill in the blanks.

by the Ethics Review Board for the Faculty of Health Sciences, Ben Gurion University of the Negev (No. 26-2020).

3. Survey results

A full listing of the survey questions is provided in Table 4; select results are presented here. The raw data may be downloaded as Supplement 1. Of the Fifty-nine students who were enrolled in the course, 42% (n = 25) responded, representing 40% (10/25) of the M3 enrollees and 44% (15/34) of the M4 enrollees. None had any formal instruction in diagnostic pathology. (Two students answered they did have such an exposure, but in their elaboration, one referred to the M1 Introduction to Pathology Course, and one referred to an online USMLE prep course, and therefore the responses were interpreted as negative.) Only 20% of respondents (n = 8) had some previous exposure to diagnostic pathology in clinical practice, 4 of whom attended a single tumor board and an additional 3 attended more than one tumor board.

Overall, the course was rated very favorably by the students: 68% (n = 17) gave at least 3 points on a 4-point scale to questions relating to how interesting the course was, how much the course improved their understanding of the covered diseases, and how strongly they would recommend a student take this course if given an option. Further, 80% (n = 20) indicated each that the course reinforced material covered in Year 2 and agreed or strongly agreed that the selective was a positive learning experience. The format of the course (specifically the 4-step cycle explained in the Methods and materials, Section 2.2) was similarly rated favorably (see the comments in Supplement 1).

The online format seems to be preferable to students, with 67% (n = 16) stating that they are more encouraged to attend the live session if it is online. The top two advantages indicated by the students were the ability to attend from anywhere (68%, n = 17) or having a recording available for later review (32%, n = 8).

The single worst disadvantage of the class, as reported by 80% of respondents (n = 20) were technical challenges in accessing the slides. In fact, due to this problem, 40% of respondents (n = 10) used screenshots taken by other students for part or all of the selective. Indeed, when planning out the selective, creating a user-friendly environment within budget was one of our primary concerns. The seven students who used CaseViewer gave more favorable comments than the five who used ImageScope or three who used QuPath (see Supplement

Table 4
Questionnaire.

Question	Format
Before this course, did you have any exposure to diagnostic pathology from the pathologist perspective? (eg rotations or electives in pathology) (If you answered yes please elaborate.)	Yes/No, elaboration open text
Before this course, did you have any exposure to diagnostic pathology from the clinician perspective? (eg tumor board at which a pathologist presented slides, department pathology meetings) (If you answered yes please elaborate.)	Yes/No, elaboration open text
On a scale of 1 (boring) to 4 (fascinating), how did you find the selective?	Scale 1–4
On a scale of 1 (not at all) to 4 (very much), how much did the selective improve your understanding of the diseases covered?	Scale 1–4
Which of the following programs did you use to view slides?	Multiple choice with an open text "other" option
How would you describe your experience with the slide viewer you used? What did you like about it, what did you struggle with?	Open text
Did you think that the format of the course (cycles of self-study, lecture, quizzed individual slide review, class-based quiz/slide review) was appropriate? What did you like/not like/would have changed about it?	Open text
On a scale of 1 (not at all) to 4 (very much), would you recommend a student should opt to take this selective if given the choice?	Scale 1–4
On a scale of 1 (not at all) to 4 (very much), how much did this selective reinforce material that you learned in Year 2?	Scale 1–4
In your opinion, what would have/could have been better about this course if it was taught in person?	Open text
If you used any resources (texts or atlases) other than what was provided by the instructor, please list them here.	Open text
Are you more encouraged to attend the live session when it is online or when it is in a classroom?	Multiple choice
What is the single best advantage for offering this course online?	Multiple choice with an open text "other" option
What is the single worst disadvantage for offering this course online?	Multiple choice with an open text "other" option
Overall, was the selective a positive learning experience?	Scale (Strength of Agree/Disagree)
Other general comments	Open text
What year are you?	Multiple choice

1). Negative reviews mainly focused on the technically difficult setup and slow connection speeds, especially related to the VPN and remote desktop setup, although the ImageScope interface was judged unfavorably by one student. One student recommended the instructors offer a tutorial on using the slide readers. The authors feel that a future offering along this format should either be accompanied by significant technical support from the school before the course begins in order to assure that everyone can access the slides, or otherwise instituting one of the other slide access methods discussed in the Materials and methods section and Supplement 2.

4. Discussion

Although M1 and M2 students are exposed to pathology in their education as part of either a dedicated introductory course (M1) or systems courses (M2), these experiences are limited to knowledge transfer and acquisition as occurs in many preclinical settings. Traditionally, very few students in their final two years have any exposure to diagnostic pathology as practiced by anatomic pathologists (Survey results, Section 3). As such, graduates have minimal familiarity with the relevance of surgical pathology in clinical practice, as well as the significance of the material that they learned in their preclinical years. The pandemic crisis that forced exclusion of medical students from the in-person patient healthcare setting provided an opportunity to expose the students to material they largely would have remained ignorant of, despite its great use in treating patients.

Overall, we believe that this selective was an excellent addition to the students' education for both technical and educational reasons. Our new slide viewing interface enabled students to truly interact with the slides as a pathologist would, including exploring the slide and zooming into interesting areas. An additional significant benefit was the ability to add IHC to the course, which had not been done until now in our regular student pathology lab exercises. The addition of IHC added a significant dimension to the students' experience, reinforcing the mechanistic understanding of neoplasia (eg c-myc overexpression in Burkitt lymphoma), indications for treatment (HER2 and ER expression in breast cancer), and other relevant aspects of clinical knowledge (extreme caution in the use of progesterone containing pills in patients with a history of meningioma, due to expression of progesterone receptor in these tumors). Additionally, having the slides available in this format allows for possible future implementation of remote learning or self-study.

The format of the present course may enrich the students' education on numerous fronts. Teaching the students with actual diagnostic pathology slides (H&E and IHC) imparted the difference between *telling* them about depth of invasion, nuclear grade, and the expression of clinically relevant proteins, versus *showing* them. At least for some students, visual perceptual learning is a valuable tool for developing expertise in general [10]. As such, certainly the skill of understanding a pathology report should be nurtured in all undergraduate students. Beyond this, basic exposure to some of the profession's specific skills – which is generally lacking in undergraduate medical education – may encourage a student to give a moment's thought to perusing a career in pathology, in the same manner that these students are rightfully taught to grade autonomic reflexes, evaluate the optic fundus, and identify acetowhite epithelium, even though most will not employ such specialized skills in the future.

Further, there was an opportunity to discuss important and advanced topics in surgical pathology to which students are usually undereducated and yet are often valuable to clinicians in practice. These included the indications, limitations, and dangers associated with sending tissue for intraoperative consult (the so-called “frozen section”); relatively new pathological diagnoses which have significant clinical impact but which are excluded from or incompletely covered in the current medical curriculum (NUT carcinoma, NIFTP); and the different roles of the pathologist in diagnosing neoplastic vs nonneoplastic diseases.

In the neuropathology pre-test described in Materials and methods, students were shown a tumor and asked to classify it as either astrocytic or oligodendroglial. On this pre-test, which comprised of 15H&E images, 28 students (70%) scored at least 13/15 correct (86%), and 7 students (17%) got 15/15 correct. Although we have no control group, we believe that these scores demonstrate some success of the course and its contribution to students' appreciation of pathological findings.

Even within the distance learning construct, there were several limitations to the development of the course. Due to the need for fast curriculum development, case selection was based in largely on availability. The course coordinator and chief teaching assistant for pathology (BS and NS, respectively) were developing some digital labs for medical students and already had some cases selected for this purpose. Additional cases were chosen based on the ease of finding high-quality slides with classic features of the disease in question, and that the instructor had a PowerPoint presentation that could be easily adapted to the new format. Within these restrictions, about 1 h was invested for curriculum planning of each module (meaning, selecting a differential diagnosis and adapting a PowerPoint presentation for this purpose), and variable time was required for preparing digital slides (depending on if slides had been pre-selected for digital labs and the ease of findings archival slides that met our quality criteria). Collectively, the course sampled from the most common diagnosis in the core of general pathology (surface epithelial neoplasia in dermatopathology, breast neoplasia) in addition to more specialized topics (neuropathology, thyroid pathology). The otherwise peculiar combination was appropriate to maintain a high level of interest in order to teach key concepts at an undergraduate level rather than the most important skills for an entry-level resident, in which case more emphasis may be placed on the common “general pathology” fields.

Another time-related restriction concerned how much time students were asked to dedicate to the course. On the one hand, this was obviously a serious educational framework which demanded appropriate commitment and investment from the students, both for the “refined” sake of their medical education and to ensure that the course met regulatory requirements for academic credit. On the other hand, we understood that many new uncertainties and expectations suddenly arose regarding fourth year rotations (for current M3 students) and residency (for current M4 students). In light of this, we made a conscientious decision to limit the time within the module so that students could secure their academic and professional frameworks for the coming year. Very unfortunately, this, in turn, limited the investment we could put into interaction with the students, and can hopefully be rectified in future offerings.

5. Conclusion

The coronavirus pandemic was international disrupter of education at all levels. It also threatened to disrupt the academic timeline of medical students, specifically those in the third and fourth years. We viewed this crisis as an opportunity to improve our online clinical rotations and specifically to attempt to enhance our students' knowledge of material that they heretofore were not exposed. Using freely available public software, professor led problem based learning and standard texts we were able to create a virtual curriculum simulating a two-week Diagnostic Pathology Selective. Based on subjective responses by students as well as objective assessments of knowledge not previously taught, we feel that the course was a success and can be a model for similar virtual pathology electives in the future, both in times of crises such as this and even during routine medical school education. The most significant improvement to the course that should be implemented in future iterations is providing greater technical support to the students before the beginning and/or use of a friendlier interface. The course demonstrated value conveying knowledge to students that will be useful for future careers as physicians, and also was able to provide

clinical experience to third-year students who might be considering a career in pathology.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.anndiagpath.2020.151612.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

BS, Conceptualization, Methodology, Investigation, Writing – Original Draft; **NS,** Writing – Review & Editing, Resources; **AJ,** Writing – Review & Editing, Resources, Supervision; **BT,** Conceptualization, Methodology, Resources, Supervision.

Declaration of competing interest

None.

Acknowledgements

Special thanks to Dr. Alon Zilka of the National Institute for Biotechnology in the Negev, Ben Gurion University, for providing us access to his lab to allow our slide set to be properly digitized.

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