Pathology education must evolve as medical knowledge expands and disruptive technologies emerge. The evolution in pathology teaching practices accelerated as traditional teaching modalities were suspended in March 2020 during the coronavirus disease 2019 (COVID-19) pandemic.

Objectives.—To provide pathologists an overview of established teaching paradigms and practical examples of how these paradigms may be applied to pathology education, emphasizing differences in graduate and undergraduate medical education as well as the challenges and promises of remote learning, as revealed by the COVID-19 pandemic.

Context.—Pathology education must evolve as medical knowledge expands and disruptive technologies emerge. However, the evolution in pathology teaching practices accelerated as traditional teaching modalities were suspended in March 2020 during the coronavirus disease 2019 (COVID-19) pandemic.

Data Sources.—Selected peer-reviewed publications representing the field of educational social science.

Conclusions.—Evidence-based methods described in education and social sciences can be effectively deployed in pathology education and especially remote learning, as necessitated by the current COVID-19 pandemic. Understanding established principles, such as cognitive load, competency-based learning, peer-assisted learning, and flipped classrooms may prove useful in developing effective, learner-centric content for pathology education.


Educational Theories and Methods

Cognitive Load

Background and Definitions.—The cognitive load concept is used in cognitive and educational psychology to describe the demands placed on working memory (WM). Established human memory models suggest our brains can take in and hold an extraordinary amount of information for a small period (milliseconds). To convert this information into long-term memory (ie, knowledge), it must be processed by WM. WM, commonly referred to as “bandwidth,” has limited capacity, and it therefore forms the bottleneck between information intake and retention. When a learner’s WM capacity is exceeded, learning and performance are impaired. Cognitive load theory posits that education can be improved by designing instruction to minimize demands on WM. Examples of cognitive load and techniques for mitigation are presented in Table 1.

Intrinsic Cognitive Load.—Intrinsic load is the effort associated with the topic at hand, for example, learning the types of pancreatic neoplasms or recognizing the difference between epithelial and mesenchymal cells. Different topics and tasks carry inherently different levels of difficulty. Cognitive load theory proposes to break bigger, more complicated concepts into smaller pieces, which can be learned more easily and then reunited. In theory, WM can process 7 pieces (“chunks” or “schemata”) of information at a time—often cited as the rationale for 7-digit phone numbers. However, recall that WM can think about or hold only 5 to 7 “chunks” of information at a time. When learning new information, students require additional mental resources to think about and remember previously learned material. The study of cognitive load theory suggests that creating a rich environment for learning and employing strategies that will engage students and help them visualize complex material can enhance learning.

In particular, the approach of cognitive load theory would be effective in pathology education. Pathology educators adapt to the changes in the historic teaching paradigm, and the comparatively small number of pathology residents and the unique nature of the specialty necessitate considering medical education research to inform how we teach, both online and in person. Given the comparatively small number of pathology residents and the distinctiveness of pathology among clinical specialties, there is a relative dearth of evidence-based approaches to pathology education. Here, we outline some of the theories, methods, and data developed for general medical education and apply them to pathology practice to help medical schools and residency programs more effectively teach pathology and pathologists. We give special emphasis to considerations in online/virtual learning, informed by our current socially distanced status.

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numbers. Expertise develops when learners can combine simple ideas into more complex ones. An advanced learner can therefore process more information in 7 chunks than a novice. Instructors should recognize that intrinsic load is higher for novice learners, and instruction should be tailored accordingly.

**Implementation.**—Graduate Medical Education.—Consideration of cognitive load is crucial to effective medical education, and pathology education in particular. Exposure to pathology is limited in medical school curricula and foreknowledge of basic pathology principles cannot be assumed. When first-year pathology residents begin training, they face a mountain of new information, skills, and systems. Breaking down these complex schemata into digestible bits is essential for efficient learning. The effect of heavy intrinsic cognitive load on novice learners should be considered, both during traditional “learning by doing” and in more formal didactic settings.

Traditional residency training is more of an apprenticeship than a curriculum. As trainees are assigned cases, they construct basic schemata for case completion, and these schemata become more complex with repeated exposure. Novice learners hold each piece of new information individually; for example, a stomach biopsy contains corkscrew-shaped glands, mucodepletion, smooth-muscle stranding, and paucity of inflammation. More advanced learners package individual bits of information into a schema recognized as reactive gastropathy. Similarly, the first time a resident grosses a uterus, they must learn to print cassettes, use the dictation system, describe the specimen, use the scalpel, and cut appropriately sized samples. As these background tasks become linked into 1 schema, the resident can instead focus on actual gross gynecologic pathologies, such as features of a neoplasm, preliminary differential diagnoses, and appropriate sampling for staging. Mastery of the basic schema, “grossing a uterus,” allows for even more complex tasks, including grossing unusual specimens (exenterations, neoadjuvant treatment effect, rare neoplasms) or peer teaching. The apprenticeship model relies on the specimens that happen to be available. Therefore, the time required to become proficient in grossing different types of specimens depends on the volume and frequency of procedures at the training institution. While this apprenticeship model may be sufficient for “simple” and common specimens, the ability to provide repetitive practice, and thus reinforce complex schemata, for complex specimens is entirely dependent on the surgery schedule. Likewise, novices in the gross room should not be first presented with rare and complex specimens; the number of elements that must be processed simultaneously to successfully gross a pelvic exenteration, for example, is prohibitive. However, the apprenticeship model dictates residents gross what happens to be on their bench that day, regardless of their proficiency. A more practical approach might be to start with didactic lectures on basic grossing techniques, continue with computer diagrams or simulations, and then provide novices real specimens requiring only basic grossing tasks, graduating to more complex specimens as proficiency is achieved.

To tailor didactic instruction appropriately, it is also crucial to recognize the level of the learner. Cognitive load can be incorporated into didactic development, both within lecture scheduling and individual lectures. Similar to the grossing example, strategies include introducing basic lectures (grossing, report writing, and normal histology) early while teaching more esoteric, subspecialized topics later. Cognitive load theory suggests instructors can lower the intrinsic load by helping students construct more complex schemata and make connections with already established knowledge. Instructors should consider how traditional organ-based lectures can build on each other to reinforce general concepts, such as neoplasia, reactive patterns, ischemia, vasculitis, autoimmune pathologies, and transplant pathology. With attention to clustering like topics at similar complexity levels, instructors can decrease the number of discrete schemata required by learners and therefore increase the capacity of WM. In pathology, such schemata can include both intraorgan and interorgan concepts, which could be interwoven, providing both repetition and schema building. At our institution, introductory subspecialty organ-based lectures are grouped (pancreas, liver, colon). This provides a framework for developing organ-specific schemata but does not take advantage of the opportunity to build neoplasia, inflammatory, or other concept-related

### Table 1. Strategies to Decrease Intrinsic and Extrinsic Load

<table>
<thead>
<tr>
<th>Cognitive Load Type</th>
<th>Mitigation Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intrinsic load</strong></td>
<td></td>
</tr>
<tr>
<td>New information</td>
<td>Tailor information to the level of the learner</td>
</tr>
<tr>
<td>Many concepts</td>
<td>Draw connections to existing knowledge</td>
</tr>
<tr>
<td>Inherently complex information</td>
<td>Keep lectures/readings short and focused</td>
</tr>
<tr>
<td><strong>Extrinsic load</strong></td>
<td>Present information in a consistent manner</td>
</tr>
<tr>
<td>Attention distractors (people, pets, email, household tasks)</td>
<td>Summarize and limit take-home points</td>
</tr>
<tr>
<td>Environmental distractors (noise, poor connection, uncomfortable set up)</td>
<td>Break down big concepts into smaller parts</td>
</tr>
<tr>
<td>Lecture complexity</td>
<td>Encourage camera use</td>
</tr>
<tr>
<td>New/multiple technologies</td>
<td>Interactive tools (annotation, small groups)</td>
</tr>
<tr>
<td></td>
<td>Chat function</td>
</tr>
<tr>
<td></td>
<td>Set expectations: quiet, comfortable, private setting, door closed</td>
</tr>
<tr>
<td></td>
<td>Minimize words on slides</td>
</tr>
<tr>
<td></td>
<td>Animations only to accentuate crucial points</td>
</tr>
<tr>
<td></td>
<td>Organization: LMS, clear and consistent communication</td>
</tr>
</tbody>
</table>

Abbreviation: LMS, learning management system.
schemata. One strategy to build interorgan schemata is to construct lectures in similar formats, using similar language applied across multiple organ systems and processes. However, using this centralized system residency-wide would increase lecturer workload and deprive lecturers of using their creativity and individual framework. As with many educational strategies, ensuring buy-in and adherence by faculty can be a challenge.

Undergraduate Medical Education.—Pathology education in medical school has regrettably continued to shrivel over the past decade. Many medical students never learn to use a microscope or evaluate glass slides. This presents a huge challenge to the pathology educator because very basic schemata are missing. An obvious but challenging solution is to incorporate basic pathology with physiology and pathophysiology in the preclinical years, including histology and molecular diagnostics. New online resources, including publicly accessible whole slide imaging platforms, provide new approaches for broadening exposure to pathology.

Traditional medical school clerkships often expect medical students to mimic and/or observe residents, who are themselves taking part in a learning apprenticeship. Because resident learning materials are tailored for resident learning, folding medical students into resident activities and didactics is often inefficient for medical student learning. Moreover, the majority of medical students will pursue specialties involving direct patient care, where the scope of pathology knowledge required is necessarily different from that of students pursuing pathology as a career. Therefore, undergraduate medical pathology educators must be especially cognizant of the needs and expertise of their learners.

For medical students pursuing careers other than pathology, linking pathology concepts and images to preexisting schemata is key. Pathology concepts can be presented in the context of common clinical scenarios, linking clinical presentations to histology and laboratory results. Pathology reports and molecular results can be discussed in a case-based format, placing the learner in the role of the ordering physician. All of these techniques take new, sometimes abstract concepts and anchor them to familiar frameworks.

Extrinsic Cognitive Load.—Extrinsic load refers to artificially induced load, an especially relevant consideration in online learning. Extrinsic load can take the form of unnecessarily complicated explanations, distracting details (complicated slides, overuse of animations, or sound effects), an uncomfortable physical environment, or, in the age of online learning, a toddler or dog interrupting a lecture. Extrinsic load can be more easily addressed by learners and educators than intrinsic load.

Implementation.—Because extrinsic load is by definition unrelated to content, mitigation strategies are similar for undergraduate and graduate education. Simple awareness of extrinsic load can help address many of its causes. Learners should be instructed to minimize distractions, such as disturbing noise, uncomfortable ambient temperature, lighting, or seating. Educators should simplify slides, ensure appropriate audio volume and lecture length, and provide adequate breaks.

A major and insidious cause of extrinsic load, whether learning is in-person, online, or on the wards, is computer multitasking. Computer and handheld device distraction are so prevalent and potent that even those not actively engaging it are affected. In one study, both students multitasking on a laptop during lectures and those near them scored lower on tests compared with those who were not multitasking. Online education requires a student to sit in front of a screen; distraction is just keystrokes away. Moreover, the delivery of lectures online reduces the interaction between educator and learner, limiting the lecturer’s ability to identify distracted learners, gauge the pace and reception of the material, and receive verbal or physical feedback in real-time. Simple strategies to engage online learners include camera usage, annotation functions (which allow participants to draw on a shared screen), peer-assisted learning, and flipped classroom models (discussed below).

A less intuitive strategy to minimize extraneous load is to ensure learning materials are well-organized and easily accessible. Most institutions use a Learning Management System to provide resources, including course overviews and expectations, daily schedules, links to lecture materials, reading assignments, and additional resources. Online learning information can be located in multiple easily accessible sites, allowing 1-click access to lectures. The easier it is for students to find the information they need, the more capacity they have to learn new material. Moreover, formal organization of and easy access to learning systems instills student confidence and trust and decreases student anxiety, especially during times of transition. Best practices for using social media platforms for medical education and strategies for assessing the accuracy of web-based content should also be provided.

Benefits and Drawbacks.—The cognitive load theory framework has been well-established in helping educators increase the effectiveness and efficiency of teaching methods. Strategies to mitigate cognitive load have become crucial due to the added challenges of online learning. However, these strategies are just as effective for in-person learning and hopefully will be carried forward past the pandemic. The major hurdle to implementation is that traditional medical education, especially pathology education, is not currently attuned to this framework. Therefore, while incorporating cognitive load concepts may improve pathology education, the resources required to implement them are significant.

Competency-Based Education

Background and Definitions.—Traditional curricula center around a series of lectures, readings, and other activities (small group work, audiovisual projects), with an assessment at the end of a defined period. Learners are graded based on exams or final projects, before moving to the next course. In contrast, competency-based education requires learners to achieve a satisfactory level of mastery of essential skills and tasks. In the last several decades, medical educators have been promoting a shift from the traditional system to competency-based education. A key consideration in competency-based education is how to define competency. In graduate medical education, the competency required is that which serves patients and the health care system. The goal is not to rank students to each other or a predetermined passing score, but to ensure learners are proficient in the tasks they will be required to perform as physicians.

Milestones.—The Accreditation Council for Graduate Medical Education has implemented a competency-based system called the “Milestone Project,” which seeks to document the progress of each trainee (resident or fellow) in specialty specific competencies (“milestones”) deemed
Table 2. Entrustable Professional Activity Supervision Levels

<table>
<thead>
<tr>
<th>Supervision Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Observation but no execution by the trainee, even with direct supervision</td>
</tr>
<tr>
<td>2</td>
<td>Execution with direct, proactive supervision</td>
</tr>
<tr>
<td>3</td>
<td>Execution with reactive supervision (ie, on request and quickly available)</td>
</tr>
<tr>
<td>4</td>
<td>Supervision at a distance and/or post hoc</td>
</tr>
<tr>
<td>5</td>
<td>Supervision provided by the trainee to more junior colleagues</td>
</tr>
</tbody>
</table>

...essential by a national committee. These milestones were not intended to serve as a curriculum framework, but as a general guide to expectations for medical graduates. Because pathology differs significantly from other clinical specialties, Pathology Milestones were significantly adapted in an attempt to cover a broad and distinct range of requirements.9

Entrustable Professional Activities.—A complimentary framework for competency-based learning is Entrustable Professional Activities (EPAs), originally defined as “tasks or responsibilities to be entrusted to the unsupervised execution by a trainee once he or she has attained sufficient specific competence.”10 Specific tasks with observable output map to the more broadly defined subcompetencies of the Milestones, often spanning multiple categories (ie, Patient Care and Medical Knowledge). Put another way, EPAs are tasks and Milestones are abilities. EPAs are assessed using the 5 levels of Supervision, as listed in Table 2 (from Ten Cate).19

Implementation.—Graduate Medical Education.—Pathology Milestones have been implemented nationally in the US, with residents and fellows assessed twice a year. Important metrics include progress over time and expected graduation levels. Results are used to identify trainees who may need additional training in specific areas. In 2017, the pathology Graduate Medical Education Committee published a set of 19 suggested EPAs for combined Anatomic and Clinical Pathology training.11 Examples include “perform gross dissection of simple and complex specimens,” “evaluate and report critical values in the clinical laboratory,” and “implement a new assay or test system.” EPAs are customizable according to each program’s requirements and allow for specific, task-related feedback for trainees. Though emphasis is traditionally placed on diagnostic accuracy, as this is the activity most often observed by pathologist educators, specific EPAs can assess tasks such as grossing efficiency, communication with clinicians, and presentation skills.

Undergraduate Medical Education.—The use of EPAs in medical school is less straightforward, as medical students are not expected to function as independent physicians (or “entrustable professionals”). EPAs for medical students have been defined as tasks and responsibilities for which a resident should be proficient on the first day of residency. The Association of American Medical Colleges published a list of 13 Core EPAs in 2014,12 and a 5-year pilot program to implement these EPAs involving 10 medical schools started soon after. Early impressions from the pilot noted the complexity of implementing and assessing EPAs uniformly across programs, and the difficulty of achieving faculty training and buy-in.13

While the responsibilities required on the first day of pathology residency are distinct from other specialties, there are pathology competencies in which nonpathologist residents should be proficient. The Association of Pathology Chairs commissioned a project to define the pathology competencies for medical education, which were posted in 2014.14 The competencies are divided into 3 areas—disease mechanisms and processes, organ system pathology, and diagnostic medicine and therapeutic pathology—and cover a broad range of topics, aiming to prepare medical students for residency and eventual clinical practice.15 They are designed to be incorporated into the early curriculum of medical education to provide a strong foundation in pathophysiologic principles.

Benefits and Drawbacks.—Although counter to the traditional medical education model, competency-based education may allow for a transition from time-based to achievement-based programs. Learners can be supported in their learning and offered flexibility to learn at a variable pace. When the University of Toronto orthopedic surgery residency implemented a competency-based curriculum based on modules, they found some learners shortened their training time, even though decreasing training time was not the goal of the program.16 Residents progressed through modules based on competency, not time, which resulted in 8 of 14 residents finishing the program in 4 years, rather than the traditional 5.

However, competency-based education is only effective if the competencies being taught and assessed are robust and valid, and the processes for mapping competencies to course material and assessments are explicit. Work is underway to determine how well pathology training programs prepare trainees for pathology practices.17 It will be important to tie the needs of actual pathology practice to resident Milestones and EPAs.

While the proposed undergraduate medical education EPAs may ease the transition from undergraduate medical education to graduate medical education, they are unlikely to address the distinct needs of pathology trainees. The Core EPAs for Residency are heavily centered on patient care and interactions, including “gather a history and perform a physical examination,” “enter and discuss orders/prescriptions,” “recognize a patient requiring urgent or emergent care and initiate evaluation and management,” and “obtain informed consent for tests and/or procedures.” Even if these activities are mapped to pathology counterparts (physical exam = gross exam, prescription = immunohistochemical stain, a patient requiring urgent care = pathology and lab medicine critical values), such activities are generally not taught in medical school and would not be entrustable at any level on day 1 of a pathology residency. Therefore, while the proposed EPAs may be an important framework for training physicians, and undoubtedly pathologists need experience in these areas, they do little to improve students’ readiness for pathology residency. Tailoring undergraduate medical education EPAs to possible specialty choice would entail even greater complexity, and, we suspect, would be unworkable.

Boot Camps

Background and Definitions.—A “boot camp” derives its name from the intense initial training period undergone...
by military recruits, designed to train the subjects in the social norms and essential tasks required of them. Similarly, a boot camp in the education setting is designed to provide comprehensive, concentrated training in an area that is largely new and quite different from students’ previous experiences.

**Implementation.**—Graduate Medical Education.—Students learning pathology master material at different rates and have diverse levels of prior experience as they enter pathology residency. Black-Shaffer et al18 detail a boot camp model as a way to address these gaps. They suggest residents work in teams in a schedule designed to optimize learning of basic pathology knowledge and skills as well as communication and presentation skills. The curriculum includes a balance between lecture and hands-on skills and includes formal training in team dynamics. Several boot camp models are described in Nariotku et al,19 most lasting 1 to 2 months. Boot camp models include activities, such as didactic instruction, supervised gross dissection, and microscopic skills development, often supplemented with simulation videos and reading. A College of American Pathologists Graduate Medical Education Committee survey found that programs that included orientation programs reported that 1-to-1 interaction with senior-level residents was the most helpful learning method (see Peer-Assisted Learning section below). While general resident feedback from most programs with orientation training was overwhelmingly positive, most did not implement evaluation metrics, and therefore specific effects on resident performance could not be assessed. Implementation of EPAs and Milestones will likely lead to a more rigorous evaluation of the efficacy of boot camps in the future.

Undergraduate Medical Education.—Pathology boot camps for graduating medical students could include a 1-week or 2-week course that would feature didactics, virtual slide sessions, and journal clubs tailored to a specialty of interest. Future family practice doctors could undergo a curriculum focusing on biopsy procurement and processing with an overview of common diagnoses encountered. Future oncologists could learn about neoplastic versus reactive processes, the utility and appropriate use of diagnostic testing, and the components of pathologic cancer staging. Future surgeons could be instructed on the risks and benefits of frozen section and margin evaluation.

**Benefits and Drawbacks.**—Data on the effectiveness of pathology boot camps are scarce, but at least 1 program reported positive results, finding postgraduate year-1 students who underwent a month-long boot camp performed at the level of postgraduate year-2 for the following academic year.20 The disadvantages of dedicated pathology boot camps include increased time commitments of faculty and loss of dedicated resident service work during boot camp training, leaving at least some clinical services uncovered. In light of these obstacles, it will be important to minimize the length of time required for a boot camp to be effective for the defined outcomes. Considerations include prerecorded lectures and online modules, which can be completed on an individual basis. The amount of investment at the beginning of training should balance the increase in efficiency throughout the academic year.

As far as we are aware, there is no published institutional experience with undergraduate medical education pathology boot camps. While we believe the benefits would be immense, especially given the current dearth of pathology education in medical school, significant hurdles to implementing such a program exist, centered around scheduling and time allocation. We can imagine 2 approaches. The first would incorporate a pathology boot camp into preexisting clerkships, specific for Family Medicine, Surgery, Obstetrics and Gynecology, and so on. This would allow medical students to participate in a pathology boot camp automatically, as part of a standard rotation, but it would take away time from a foundational clerkship. Alternatively, specialty specific pathology boot camps could be a separate 1-week to 2-week rotation. We suspect this would be unworkable, given the difficulty in scheduling, for example, all future surgeons during the same time frame.

**Peer-Assisted Learning**

**Background and Definitions.**—Peer-assisted learning (PAL) encompasses all manners of peer-to-peer teaching, facilitation, mentoring, and assessment. PAL has been well-researched in a variety of settings, including in general education, procedural/skills learning, perceived benefits from participants, and objective impact on short-term and long-term learning. PAL in its modern application gained traction in the 1970s, introduced to the United States as “supplemental instructions” to be used in all stages of education.21

**Implementation.**—Graduate Medical Education.—Many institutions hire teaching assistants or appoint student educators in formal didactic settings. In many cases, PAL is driven by the perceived unmet needs of a student body or serves as supplemental reinforcement for traditional learning models. In graduate medical education, PAL has traditionally been implemented in a hierarchic “near-peer” manner, with more experienced senior trainees teaching junior trainees, usually owing to resource limitation of higher expertise (eg, teaching assistants for professors or senior/chief residents for attendings). Incorporation of PAL in pathology residency includes senior resident or fellow-led educational sessions for example, didactic lectures, slide sessions, grossing instruction, and individual mentorship. Other informal examples of PAL include resident study groups for board examinations or collaborative digital material/wikis as trainees progress through their years.

Undergraduate Medical Education.—Traditional forms of PAL relied upon high-performing students to tutor more junior students as a replacement teacher. This model evolved to same-year PAL models in which both parties benefit from the interaction. An early form of PAL was problem-based learning, often involving student tutors moderating small group sessions.22 This is recapitulated with laboratory and skills-based procedural learning, such as in anatomy lab,23 blood draw, basic surgical techniques, dentistry, and physiotherapy.24

**Benefits and Drawbacks.**—PAL is associated with better attendance, deeper learning, and higher exam scores.25 Students feel more comfortable with peer teachers. In addition, peer tutors are more receptive to student feedback and report greater investment in student exam success.26 The positive effects of PAL are likely attributed to the cognitive and social congruence of students with their peer teachers.27,28

Another vital component of PAL is the establishment of educational culture and environment that promotes teaching as a crucial part of learning in general, a culture of learning. This culture is especially important in medical education, where roles are in flux throughout training and
practice. Residents often switch from being a student to a teacher. Attending physicians also engage in the learning culture by peer teaching, staff teaching and training, and continuing medical education and conferences (Table 3).

Potential drawbacks of peer teaching include lack of real-life experience and specialty expertise among trainees. The literature is also conflicting on the effectiveness of PAL. While some studies demonstrate better performance in subjects/procedures when taught by peers compared with professors, several publications failed to show benefit or improvement with PAL. 

### Flipped Classroom

**Background and Definitions.** The flipped classroom (FC) method of instruction is an educational paradigm introduced in the 1990s in which the instructor uses class time for engagement and application as opposed to simple knowledge transfer. Traditional classrooms involve an in-class lecture or didactic, followed by learner knowledge application and reinforcement outside of class in the form of homework and studying. FC involves students viewing or listening to material outside of class and spending in-class time demonstrating knowledge application and synthesis, often with collaborative small group sessions and activities. The FC model promotes a shift from passive to active learning, emphasizing a single topic to replacement of an entire didactic curriculum. FC has gained momentum in recent years, attributed to the flexibility of self-directed learning, the opportunity for collaborative learning during small group discussions, and the more effective use of instructional time by both learners and educators. The rise in FC popularity has also been bolstered by technologic advances that allow students access to online content and remote class participation (Table 4).

**Implementation.**—Graduate Medical Education.—In a survey of 227 Internal Medicine Residency Program Directors, only 25 reported FC implementation “somewhat or very often,” although many (if not most) probably employ elements of FC, perhaps unknowingly. FC implementation within pathology training programs is not well represented in the literature, with limited examples described in cytopathology, dermatopathology, and informatics. However, the concept of FC is achieved by many typical activities within pathology residencies, such as journal club, case previewing and report write-up, unknown slide sessions requiring slide previewing, and gross-organ review sessions.

**Undergraduate Medical Education.**—FC can be incorporated into a medical curriculum in many ways, ranging from emphasizing a single topic to replacement of an entire didactic curriculum. For medical students, it may be especially important for in-class instruction to involve equipment or material not available at home. In pathology, examples include physical contact with gross organs, anatomic dissection, and technical activities, such as frozen sections and cytologic preparations.

### Table 3. Benefits of Peer-Assisted Learning by Organizational Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Benefits</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional</td>
<td>Serves more students while maintaining student-to-teacher ratio</td>
<td>Protected time off from rotations for teaching activities</td>
</tr>
<tr>
<td></td>
<td>Allows additional courses without the need to hire additional faculty</td>
<td>Offering course credit for teaching assistant roles</td>
</tr>
<tr>
<td>Peer tutor</td>
<td>Establishes an educational culture of lifelong learning and teaching</td>
<td>Resident-run slides sessions, board exam study, onboarding to new rotations</td>
</tr>
<tr>
<td></td>
<td>Increases confidence in material comprehension</td>
<td>Individual mentorship from senior-level trainees</td>
</tr>
<tr>
<td>Peer learner</td>
<td>Creates a more relaxed and cooperative environment</td>
<td>Attendance in peer-led small group sessions</td>
</tr>
</tbody>
</table>

### Table 4. Virtual Implementation of Flipped Classroom Activities

<table>
<thead>
<tr>
<th>Application</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web-based video communication (eg, Zoom(^a), Jabber(^b), Webex(^c))</td>
<td>Allow small-group discussions (some with breakout sessions features)</td>
</tr>
<tr>
<td>Web-based digital slide repositories (eg, PathPresenter(^d), Kiko(^e), WIDYX(^f), The Rosai Collection(^g))</td>
<td>Allow the ability to screen-share applications</td>
</tr>
<tr>
<td>Shared Documents (eg, Google Documents(^h), Microsoft OneDrive(^i))</td>
<td>Annotation, camera and chat functions encourage active engagement</td>
</tr>
<tr>
<td>Web-based digital slide repositories allow real-time slide examination</td>
<td>Web-based digital slide repositories allow real-time slide examination</td>
</tr>
<tr>
<td>combined with screen-share (Zoom), students can annotate regions of interest</td>
<td>combined with screen-share (Zoom), students can annotate regions of interest</td>
</tr>
<tr>
<td>on a digitized image and pose questions to the presenter in real-time</td>
<td>on a digitized image and pose questions to the presenter in real-time</td>
</tr>
<tr>
<td>Shared documents allow students to collaborate in real-time on small</td>
<td>Small group projects and case-based learning</td>
</tr>
<tr>
<td>group projects and case-based learning</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Zoom Video Communications, Inc., San Jose, California.
\(^b\) Jabber, Cisco Systems, San Jose, California.
\(^c\) Webex, Cisco Systems, San Jose, California.
\(^h\) Google LLC, Mountain View, California.
\(^i\) Microsoft Corporation, Redmond, Washington.
Benefits and Drawbacks.—Students report feeling more motivated and engaged in FC and they prefer the flexibility that online and on-demand materials allow.36,41,42 Students in FC may engage in more active learning and have more chances to demonstrate and apply knowledge during class time with greater access to instructors who can provide immediate feedback. During the clinical years of medical school education and residency, FC allows students to benefit from expert guidance while performing activities that mimic future practice.

Although students subjectively prefer FC,42,43 data on objective knowledge retention and improved performance are less clear.44 In a review of 82 articles, Chen et al41 report that most controlled studies describe subjective metrics, focusing on learners’ perceptions in their knowledge and skills. There are limited data on improved student outcomes. In addition, most research on FC is based either on undergraduate education or preclinical settings in graduate medical education. The ultimate goal of better patient outcomes owing to FC educated physicians is yet to be demonstrated.

Another significant drawback of FC is resource limitation on both teachers and learners. Effective FC requires the development of robust preclass material as well as flexible in-person instruction during class time. These requirements are challenging in medical settings where there is fewer teaching assistants with often less time dedicated to education. Kraut et al45 report in a review of 10 papers that learner satisfaction largely depends on the quality and ease-of-use of various modalities, with emphasis on high-production quality videos. Furthermore, a meta-analysis performed by Gillette et al46 comparing final examination and course scores found minimal gains in FC while requiring more upfront investment in time and effort, the latter also reported by other studies.27,47,48 Even modest gains in knowledge retention may also come at a cost, as seen in the report by Tang et al49 of 95 students in an ophthalmology clerkship. The FC group performed better on a posttest (with similar pretest performance between the 3 groups), however, it also reported greater burden and pressure. Of students who were unwilling to participate in future FCs, the most cited reason was the greater time commitment for preclass work.32 These findings indicate that while FC has a high potential for student/trainee satisfaction and team-building benefits, outcomes are heavily dependent on how FC material and activities are implemented.

SUMMARY

As general strategies for medical education evolve, it is important to understand the implications for pathology. Pathology education was undergoing a slow transition from a focus on apprenticeship supplemented with teaching sessions delivered in a standard lecture using PowerPoint slides to experimentation with techniques that actively engage the learner, meeting them at their level of expertise. The COVID-19 pandemic accelerated change in pathology education and offers an unprecedented opportunity to evaluate current methods of pathology education. Because of the pervasiveness of the internet and the proliferation of digital technologies, web-based teaching had been working its way into pathology education. New web-based tools being developed and deployed for remote learning during a pandemic can be implemented not simply as a stop-gap method but to improve pathology education moving forward. The incorporation of evidence-based medical education theory into teaching tools is particularly relevant as we rapidly develop and deploy remote pathology education (Table 5). We strongly believe this crisis provides an opportunity to evaluate, innovate, and dramatically improve pathology medical education. As in so many areas, we expect techniques developed and improved upon because of necessity during the COVID-19 pandemic will be carried forward after this crisis is over.

Although a comprehensive review of cognitive psychology and critical thinking is out of scope for this review, an effort has been made to focus on specific strategies most relevant to teaching pathology. The concepts of cognitive load, competency-based learning, boot camps, flipped classroom, and peer-assisted learning have been discussed and practical examples provided for implementation in pathology teaching. The teaching of pathology will continue to evolve as circumstances and technologic advances impact education. Understanding and employing evidence-based teaching strategies will help pathology educators achieve greater success and positively influence both future and practicing pathologists.

References

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