Journal of Pathology Informatics 13 (2022) 100132

Contents lists available at ScienceDirect

Journal of Pathology Informatics

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

Review Article

A review of web-based application of online learning in pathology and laboratory medicine

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ARTICLE INFO

Keywords:
Laboratory medicine
Curriculum
Online
Website
Education
Testing

ABSTRACT

Web-based learning applications can support health sciences education, including knowledge acquisition in pathology and laboratory medicine. Websites can be developed to provide learning content, assessments, and products supporting pathology education. In this paper, we review informatics principles, practices, and procedures involved with educational website development in the context of existing websites and published studies of educational website usage outcomes, including that of the authors. We provide an overview with analysis of potential results of usage to inform how such websites may be used, and to guide further development. We discuss the value of educational websites for individual users, educational institutions, and professional organizations. Educational websites may offer assessments that are formative, for learning itself, as practice, preparation, and self-assessment. Open access websites have the advantage of worldwide availability 24/7, particularly aiding persons in low resource settings. Commercial offerings for educational support in formal curricula are beyond the scope of this review. This review is intended to guide those interested in website development to support non-commercial educational purposes for users seeking to improve their knowledge and diagnostic skills supporting careers in pathology.

Contents

Educational content development: Competencies, goals, and objectives

Web-based education in pathology and laboratory medicine is a facet of pathology informatics guiding design, programming, and online delivery of instructional content. However, the basis for developing instructional content involves defining learning competencies, goals, and objectives for the content. A competency defines the ability to perform a task in a job setting and is generally stated as a broad domain of performance. The 6 core competencies defined by the Accreditation Council for Graduate Medical Education (ACGME) are: patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and systems-based practice. These competencies, along with goals and objectives specific to the level of training for pathology residency, have been promulgated by the Accreditation Council for Graduate Medical Education (ACGME).[1]

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http://dx.doi.org/10.1016/j.jpi.2022.100132
Received 6 May 2022Received in revised form 2 August 2022Accepted 4 August 2022
Available online 09 August 2022

Web-based education largely involve the knowledge competency: acquisition and application of information. However, developing a base of knowledge is a starting point for mastering other competencies such as patient care. Web applications that occur in a virtual setting may include not only visual, but also auditory and kinesthetic (moving a mouse or using a touch screen) modes of learning. Such performance-based applications may aid the learner in acquiring and using knowledge about tasks involving multiple competencies in a real job setting.

A goal defines the general purpose for a teaching activity such as a lecture, group discussion, or web-based exercise. An objective describes a measurable and specific performance outcome that learners should be able to demonstrate in order to be considered competent. An objective describes an intended instructional outcome, not the process of instruction. Use of an objective helps to determine if a goal was achieved. An objective describes the intended outcome in terms of performance.

Instruction may include a criterion of acceptable performance indicating how well the learner performed. Objectives aid in development of both educational content and assessments. Objectives developed in the context of a learning activity must define an outcome and must include a verb that directs the learner to accomplish a task. Examples: “The learner will be able to interpret the result of a high sensitivity troponin assay” or “The learner will be able to define machine learning in the context of whole slide imaging data content.” Goals and objectives often overlap in practice when objectives are defined broadly or goals are narrowly focused.

An example of objective usage involves the authors’ website, with content areas and objectives for development of tutorials and assessments in laboratory medicine guided by a curriculum published in 2010 in the American Journal of Clinical Pathology (AJCP) outlining 6 content areas of laboratory medicine: foundations of laboratory medicine, chemical pathology and immunology, molecular diagnostics, hematology, microbiology, and transfusion medicine. Within each of these content areas were 7–13 objectives.[2]

Based upon the published laboratory medicine curriculum, our project began in 2015 for the purpose of deploying the objectives of those documents in a freely accessible web-based format using a set of tutorials for each of the 6 content areas. The level of learning was set beyond introductory, with prior formal instruction in pathophysiology of disease in a training program. We did not aim for an expert level of knowledge to be presented. Each tutorial provided instruction on each of the objectives. The rationale for choosing succinct presentation of content in the tutorials was based upon a study of reading rates, showing that when reading for an examination, the rate is 50–100 words per minute.[3] Content creation of web pages was guided by usage of reference sources including Choosing Wisely®, Robbins and Cotran Pathologic Basis of Disease 9th edition, Harrison’s Principles of Internal Medicine 18th edition, and Medscape®.[4–7]

We developed sets of formative assessments to align with the content areas and objectives. Questions were composed in vignette format to promote participant interpretation of information in the modules and to enhance the application of reasoning skills. There is some validity evidence that test-takers' descriptions of their cognitive processes during completion of high-quality clinical-vignette MCQs align with processes expected in real-world clinical reasoning. This supports one of the assumptions important for interpretations of multiple choice question (MCQ) examination scores as meaningful measures of clinical reasoning.[8] The tutorials and assessments were placed on a world wide website with free internet access available for use 24/7.

Subsequent to publishing of the proposed curriculum in 2010, the American Board of Internal Medicine and the American Society for Clinical Pathology began collaboration in 2012 on the initiative to develop the Choosing Wisely® campaign with the goal to create medical specialty-specific lists of “things physicians and patients should question.” These lists included items pertinent to laboratory medicine testing. The ABIM and ASCP received input from over 70 medical specialty societies since the launch of Choosing Wisely®. We employed the information from Choosing Wisely® to revise our modules and quizzes in 2021, updating them to follow the curriculum map more accurately and completely.[4]

Client-side or server-side web development?

Developing web applications requires client-side or server-side programming skills. **A client-side script is a program that** runs on an end user's own device such as a computer, tablet, or mobile phone. Client-side “front-end” development focuses on creating a website with which the user can interact: page layout, user interface, visual elements displayed, and form validation of user input. Programming typically involves entry level coding using Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript. The end user can view any web page coding via a web browser (e.g., “show page source”) and copy it.[9,10]

A browser “plug-in” application or “app” may be installed on the user’s device to allow programming code to run client-side. However, if the app requires a large amount of storage space or processing memory on the user’s device, then it takes up resources of space and speed for other applications. Cloud computing has become popular as online network geographic coverage and access speed have advanced. Cloud refers to online accessible programming and data storage somewhere on earth and transparent to the user. Cloud resources do not have to be run or stored locally and remain with the internet service provider.[11]

Server-side development involves **scripts processed on the web server when the user’s web browser requests information**. Such programs run only on a web server and can be termed "back-end" development. The end user interacts with a web server to retrieve or enter information. A common server-side task is dynamic interaction with a database, exemplified by end users ordering a product by shopping online. When the client base includes many end users with mobile devices, then applications requiring intensive processing should be server-side.[12]

Server-side developers may employ programming languages such as Java, Python, and Ruby which are object-oriented, or employ structured query language (SQL) for interacting with and manipulating data in databases. Hypertext preprocessor (PHP) and practical extraction and report language (Perl) are scripting languages to create websites and web applications. Wordpress® is an example of a content management system that utilizes PHP and SGL and a plugin architecture and template system to assist in website development. Server-side programming is a way to provide a layer of security. Data is not inherently exposed when it remains on the server and is not transferred to the end user. The entry points to the data are less exposed when the service layer to access is hidden from the end user.[13,14]

The nature and complexity of the programming needed for a website depend upon the goals for the end user and the developers (commercial, academic, or private) and the sponsoring organization, if any. Common goals for client-side website development other than display of text include creation of visual effects and navigational menus. Adding or changing website content often involves uploading a file to the server. Hence, client-side development is best for developers at the entry level of website creation and programming.

Server-side development focuses more on webpage interaction with databases and retrieval of information from a web server. Altering content and website interaction requires more extensive programming skill than just modifying a single file. Client-side user input can be collected via a javascript “cookie” that remains on the users device. Server-side PHP can take user input and connect it to a database for permanent storage. Client-side user input is inherently less secure, depending upon the security of the user’s device. Server-side input can be made more secure, but is a likelier target for a cyberattack.

Once a website is created, it must be maintained. Costs may include ongoing design, programming, marketing, and site maintenance including hardware and connectivity infrastructure. A website hosting service may provide the infrastructure as well as costs of domain and secure sockets layer (SSL) certificate.[14] Consideration for assignment of responsibilities for persons within an organization is needed to determine who maintains the website. The learning curve for client-side applications is not as steep as for server-side, where dedicated information technology (IT) staff may be needed. Medically related content requires review, revision, and updating on a regular basis to keep pace with the advancements in knowledge and applications in medicine. Websites with outdated content can become an embarrassment to individuals and institutions.[15]

Educational website goals

The goals for an educational website need consideration. Individual faculty at an educational institution, or an organizations such as the Association for Pathology Informatics (API) may consider developing and maintaining such a website. Will the purpose be primarily making informational content available, or providing specific content with assessment associated with a program of instruction leading to a degree or certification, or marketing of educational products? Minimal programming skills and resources are needed to provide content only as web pages, and as open access. Requiring a login and password for access requires more IT skills, and/or usage of a commercial learning management system (LMS) product. Marketing of educational products such as journals, print or electronic publications, continuing education, or conference participation requires interaction with databases and server-side programming.

If a goal for a website offering is educational, in addition to instructional content, assessments may be offered. Assessments of learning are formative or summative. Formative testing occurs for learning itself, as practice, preparation, and self-assessment. Summative testing involves obtaining a score for achievement of a grade or passing a course in a formal educational program granting a degree or certificate. Formative assessments are suited to client-side programming. Summative testing requires validation with security of testing instruments as well as security of scores achieved in a stable database best accomplished with server-side development.

The alternative to a website with an open access URL is a dedicated LMS for an educational institution, which limits access via login and password. Usage of an LMS is common for undergraduate colleges and universities as well as graduate health sciences education programs. The cost per user diminishes with larger enrollments. Hence, such usage is not common for postgraduate residency and fellowship training programs. Examples of commercial LMS products include Blackboard® (https://www.blackboard.com/) and Canvas® (https://community.canvaslms.com/). A freeware LMS product is Moodle (https://moodle.com/solutions/lms/) but it requires programming skills to deploy it. The LMS can provide a means for content delivery, and even formative as well as summative assessments, but may have limited customization capabilities.

Much of the authors' website is an example of open access, client-side development for web page display of informational content along with formative assessments of knowledge. Individual web pages use HTML coding with CSS for visual formatting and animations. The assessments utilize Javascript cookies for scoring of end user input. All of the web page files can be individually edited and uploaded to the server without any server-side programming required. The only IT support required is maintenance of the web server.

The authors' usage of server-side programming is illustrated by formative assessments in the Laboratory Medicine Curriculum.[16] Each test has a JavaScript "form" element to capture and record responses of participants. Each participant is provided with a pop-up login window upon test startup, informing the voluntary opportunity to take a test with anonymous tracking of results, such that no **individual can be identified in the raw data, as approved by the institutional review board in accordance with ethical standards established by the institution (Mercer University IRB No. H1006137)**. A pick list is given for participants to choose: medical student, resident in training, physician in practice, health sciences student, health sciences professional in practice, or other. This anonymous login is captured, along with the field of study, the date and time the quiz was completed, and the individual question responses, and appended to a log file on the web server. The Javascript form capturing input is processed via a web server perl script to return a score and key to participants while writing the users' results to a file on the server which can be analyzed for usage patterns.

Open or closed website access

When websites are developed for the purpose of getting noticed by persons outside of an institution or organization, sharing what the developers and contributors as individuals or groups deem valuable content and expertise, then internet open access is desired. This avoids the problem of maintaining subscriber lists for login and password access to a website.

How does a website noticed? Internet search engines utilize an electronic robot ("bot") to automatically search, scan, and index websites. Website indexing can be influenced by the way web pages are formatted and by their content. However, bots are designed to also scan the "meta tags" contained in the header of the HTML code of a web page. Beware of websites offering to check on the rank of your site that may be marketing tools selling a service. Website design providing nested menus and more web page links can increase traffic directed from search engines. Regardless of design methods, the site content matters in attracting traffic to the site. Pathology as a branch of medicine has less than 2% of all medical doctors, so pathology websites cannot compete for traffic with sites appealing to a larger base of health care professionals.[17–19]

In 2013, the White House Office of Science and Technology Policy (OSTP) issued a **policy memorandum which** directed federal agencies to develop policies to make federally funded research publications and data freely available to the public.[20] Data.gov was launched in 2009 and is managed and hosted by the U.S. General Services Administration, Technology Transformation Service. It offers data, tools, and resources to conduct research, develop web and mobile applications, and design data visualizations. The OPEN Government Data Act of 2018 implements Title II of the Foundations for Evidence-Based Policymaking Act and makes Data.gov a requirement for federal agencies to publish their information online as open data using standardized, machine-readable data formats, with their metadata included in the Data.gov catalog.[21]

U.S. government works are in the public domain, not protected by the U.S. Copyright Act. Such works can be freely used in the U.S. without obtaining permission or paying a copyright fee. They can be edited, adapted, and republished without permission. The general rule is that works created by federal government employees are in the public domain, but works created by contractors, freelancers, and certain people who work with the U.S. government but aren't considered government employees for copyright purposes may be excluded from this rule.

Closed access websites are largely in two categories. Institutions, particularly academic institutions, but also health care systems, may elect to limit access to their own trainees and employees for the purpose of providing information specific to their educational programs and organizational needs. Persons training or employed at those institutions have contractual arrangements for services and resources supported through funding specifically for those persons. Organizations, particularly professional organizations such as the Association for Pathology Informatics, the American Society for Clinical Pathology, and the College of American Pathologists, have paid memberships to support funding for websites catering specifically to their members.

Purposes for pathology education websites

Internet hosting is a way for individuals not affiliated or working with an institution or organization, who want to share their expertise in a more organized way than on social media platforms. Commercial hosting sites come with a fee, but do offer a stable platform with open access and maintained web server. Websites created on such platforms are largely limited to client-side applications. There is simplicity in uploading individual files, without the need for advanced programming skills. Use of an internet search engine will yield information and tutorials describing tools and methods for website development. Tutorials with examples for creating HTML code, CSS applications, and Javascript programs are readily available on the internet. Persons choosing this individual approach to website creation can develop the files for web pages on their own computer and troubleshoot as the pages are developed.

A key prerequisite for development of a quality educational website representing institutions and organizations is input and review of content by subject matter experts. If the primary purpose for the website is contribution to professional education in pathology, then effort to create valuable content matters more than producing visual appeal. Advocacy for advancement of pathology as a profession may be a focus for developing website content for organizations such as the CAP and ASCP. If the content of a website is for a wider audience, including those in health care but non-experts in pathology, or even the general public, then care must be taken to provide understandable information for novice learners without background knowledge in the subject matter. An example of a website for the general public interested in health care, and based upon source peer-reviewed scientific research, is the sponsored by the National Health Service of the United Kingdom.[22]

Websites started by an individual or group of persons may grow into multidimensional sites with extensive resources from contributions by many other persons. The website may include advertisements from vendors providing some financial support for site development and maintenance. An example of such a site is PathologyOutlines.[23] Another example is GP-HELPER, available as a smartphone app linking the user to multiple resources for pathology-related information and consultation.[24]

Though not strictly websites with client-side or server-side web programming features, social media sites and hosting services such as YouTube channels provide a way of posting content, particularly in the form of blogs or videos. An example is PathCast, which provides online lectures in pathology. It grew from lectures developed in a pathology residency training program. The number of and variety of offerings increased over time, along with the access modality through multiple platforms. It is an example of growing educational content incrementally, with the challenge of organizing the growing content.[25]

Institutional websites for pathology education are largely academic, but may also represent health care systems catering to staff with support for training on institutional policies and procedures, as well as continuing education. Web page development with educational content serves the primary purpose of supporting a training program, providing trainees the opportunities to acquire knowledge and learn informatics skills while providing a learning resource for the institution and others outside the institution. An example is sponsored by the University of Pittsburgh Medical Center.[26]

Academic institutional faculty teaching courses may develop web-based resources both for internal usage as well as open access. An example is at the University of Michigan Medical School.[27]

Organizational websites develop educational content to support their members. Some of the content may be open access when it is largely informational. Such content can serve as advertising for the purpose and goals of the organization, and may call attention to the value of the organization for providing learning resources. An example is sponsored by the Association for Pathology Informatics. As stated at the website, "Pathology Informatics Essentials for Residents, or PIER. i*s a research-based instructional resource that presents training topics, implementation strategies and resource options for program directors and faculty to effectively provide informatics training to their residents and meet ACGME informatics milestone requirements. PIER is also an effective resource for aspiring specialists to develop prerequisite pathology informatics knowledge and skills prior to advanced training or fellowships*."[28]

Visual interpretive skills for diagnostic work are essential in pathology, and websites may aid in developing or validating such skills. As an example, an oral pathology website, accessible by password, was developed to 76 high-quality whole slide images, including z-stacking to mimic use of a real microscope for viewing sections of the tooth, oral structures, and development of tooth and facial regions. For learning purposes, slides are annotated by content experts to identify major structural components within a tissue section, and users can either "show" or "hide" the annotations, which allows them to self-test.[29]

Another example of a website offering thin prep Pap smear virtual slides for diagnosis in psychopathology allows users to create an account for access. Whole slide images can be viewed, and a thumbnail gallery of pertinent findings is also included for guidance.[30]

How are educational websites used?

Does educational web page design affect usage and outcomes? One study used eye tracking to assess differences in usage and was based upon the concept of a web object as a structured group of words or a multimedia resource on a web page and with metadata describing its content. Web objects are meant to capture the attention of users and to characterize the content of a website, which can be further defined as electronic learning objects based upon learning objectives. That study suggested the attention paid to a learning object may be related to a learner's background knowledge, personal experiences, and learning style. Significant differences exist among learners, but successful learners tend to devote more attention and spend more time on the learning process.[31]

The authors' website is based upon learning objectives as objects, but how learners use them can vary. A prior publication describing usage of quizzes in pathology at our website showed that quizzes listed higher in the web page menu got greater usage, and completion rates also tended to fall with quizzes lower down on the list.[32]

A study of undergraduate, graduate, and dental school student usage of closed access histology course materials available on a website accessible by smartphone/tablet computer or laptop/desktop computer showed that not all students had access to all of these devices and that ease of access was important for acceptance, including the ability to download and/or view the website materials in different formats. Almost half of students wanted availability of a screen size larger than a smartphone or tablet. One consequence was substitution of the website for existing learning modalities, with over two-thirds of students forgoing use of textbooks, and over a third ceasing to use virtual slides. A majority of students did use the resource material at least 2 or 3 times, good for reinforcement, but a majority also used them a day or less before a summative quiz or exam, not so good for self-directed learning toward knowledge deficiencies.[33]

For client-side applications, tracking usage is challenging. One can track "hits" to web pages with an applications such as Google Analytics (https://analytics.withgoogle.com). However, the reports returned do not indicate how long users stayed on a page and gained any knowledge from it. Analytics do not indicate whether users were individuals with a background and interest in the subject matter, or merely surfing. Client-side assessments store test scores in cookies on the users' devices, so how well users perform cannot be determined.

As an example, the authors' website has a raw count of over 100 million hits per year, but breaking it down to individual pages yields no more useful information.[16] A "hit" does not inform whether an end user even read or viewed page content fully. The numerous client-side quiz offerings yield no results on scores. It is rare to have end users send an email concerning a web page or test question.

For server-side applications, programming to capture form data to server log files can yield information about the number of users, characteristics of users, what was accessed, and scores for assessments. However, the preparation of users from prior knowledge or current study of subject knowledge for assessment, and the motivation of users for achievement, are unknowns. As an example, the authors' Laboratory Medicine Curriculum portion of their website has sets of quizzes developed with multiple choice questions uniquely composed to cover content of learning modules that can be studied prior to taking the quizzes. These quizzes simulate a timed examination, with up to 90 s per question to complete a test. Different questions were used on pre- and posttests for a module in order to facilitate coverage of as many objectives as possible. Upon submission of results, a participant was provided with a score and answer key for the test.

Each test used a JavaScript "form" element to capture and record responses of participants. A pick list of fields of study was given for participants to choose: medical student, resident in training, physician in practice, health sciences student, health sciences professional in practice, or other. This anonymous login was captured, along with the field of study, the date and time the quiz was completed, and the individual question responses, and recorded and appended to a log file on the web server.

Upon participant exit from a test, the data were written and continuously appended to a log file utilizing a Practical Extraction and Report Language (Perl) script. The 10 log files recording responses from January, 2016 to July, 2021, were downloaded from the web server and captured into Excel® spreadsheets. The spreadsheets were analyzed to identify total logins and scores for quizzes taken by participants. Entries were categorized as complete when an answer was recorded for all quiz questions, while incomplete entries lacked one or more answers to questions for a quiz.

The score results for the 5 pretests and 5 posttests are shown in Table A1. Total entries included all logins for all tests, while only those logins with completion of all questions for a test were counted as completed entries. The range of scores was recorded for the 5 questions in each test. The overall completion rate for all 10 quizzes was 80.61%, with range of 73.55%–89.00%. (Table A1) For completed quizzes, the average score for pretests was 60.11% compared with an average score of 68.28% for posttests. The comparison of score results with repeated measures ANOVA calculation, from pre- to posttest, shows a significant ($P < 0.05$) overall score increase for only the first test, with the highest number of completed entries. For the set of tests together $P = 0.092$ from pre- to posttest scores.

A shown in Table A1, completion rates of the posttest were lower for the last 4 module tests and higher only for the first module. More consistent scoring in higher ranges was observed for participants taking posttests (Fig. A1). There were no significant differences in pretest and posttest usage within the categories of participants by training and profession for all completed tests. The mean score improved with completion, higher from pre- to posttest, for all modules except the second, but was significant ($P < 0.05$) only for the first module. Fig. A2 shows that improvement in mean score was attributable to more participants scoring at higher ranges, compared with pretests. Since the questions were different for pre- and post- tests, an exact comparison of performance improvement is not possible, given that each question covered a different objective.

If publishing the results of website usage is desired, then the nature of the usage and the identity of users must be considered as part of human subjects research guided by ethical principles. Institutional review board (IRB) overview with review and approval of any endeavor involving human subjects in research is required. For open access websites collecting data, the IRB category of "anonymous web survey" typically applies when there is no data collected that can identify individual users.

Website usage outcomes and value to users

As shown by the results from the authors' own website quiz usage, the goal of improving performance for learning objectives is difficult to demonstrate when usage is open access and not part of a formal curriculum. However, improvement does occur for demonstrated improvement in performance. User preparation, participation, and motivation are enhanced when website usage is tied to a formal curriculum with assessments having requirements for a level of achievement commensurate with granting of a degree or certificate. Achievement may be documented by quantitative means: obtaining an assessment score at a passing level. Passing a course of study may also include a qualitative assessment of having participated in website study.

Most educational institutions create objective assessments as multiple choice question examinations and define numeric passing standards. Developing a website assessment for summative purposes, counting for attainment of a degree or certificate, is a complex process. The security of assessments requires stringent environmental controls on individual access and results. The verification of user identity, security of user login, security of the assessment contents, and the access to score reports are necessary components of so-called "high stakes" assessments with potential failure of users to achieve their desired result for career success. There are commercially available applications such as ExamSoft® (https://examsoft.com) and ExamMaster® (https://www.exammaster.com) that allow development, scoring, and analysis of trainee assessments in a secure environment and with robust statistical analyses. The most secure method is via proctored test taking.

Utilizing a potential worldwide distribution, anonymous online web-based access can increase participation, provide flexibility in time and place for participation, and be cost-effective without the need for direct supervision for administering tests and collecting results for formative assessments. However, anyone can input responses and not be motivated to fully participate in a manner to support performance improvement with the instructional content and assessments provided, so the results of website usage represent a potential mixed level of participation. We could not reliably identify unique users and therefore could not track total number of test attempts nor timing among them, or whether modules were studied between pre- and posttests events. The continued exponential growth of World Wide Web content has a dilutional effect upon user searches for relevant instructional content, even if evidence-based, for presumed educational value.

Thus, voluntary and anonymous participation may yield lower completion rates and documented performance improvement. Analysis of results from an online course to improve knowledge in antimicrobial resistance showed that a total of 227 participants registered to participate in 20 assessed courses encompassing five learning modules. The number of participants completing the post-course test ranged from 31.5% to 90%. A comparison of pre- and post-test performance for the individual courses showed a statistically significant improvement in just 13 of 20 assessed courses.[34]

It is difficult to analyze participant performance in relation to specific curriculum objectives based upon the diversity of participation. Not every participant will have studied or retained knowledge of all laboratory medicine content and objective areas in a training program or subsequent continuing education activities. It is difficult to develop questions that will consistently score within a specified range, particularly for a diverse group of test-takers. The difficulty level for questions may relate more to the nature of the content area and knowledge being tested. Our highest scoring question was in the posttest for module 1 on the concept of establishment of laboratory test ranges and the knowledge of 95% confidence limits in choosing the range. The lowest scoring question was in the pretest for module 1 on the concept of serial laboratory testing and the knowledge that increased health care costs ensue with such indiscriminate testing.

One example of more formal web-based assessment is the massive open online course (MOOC) covering multiple content areas and the potential for participants anywhere on earth to earn a degree or certificate. MOOC usage worldwide can have usage patterns similar to ours with participation diminishing from start to finish. In a study of an interactive 4 week long MOOC in antimicrobial stewardship to improve prescribing within clinical teams, 32,944 people initially enrolled, 70% of whom were health care professionals. Of 15,571 persons joining the first run of the course, 5496 were active learners, 1506 fully participated, and 419 completing assignments. By course run 4, there were 5585 joiners, 1848 active learners, 427 fully participating, and 162 completing assignments. A Certificate of Achievement could be earned by learners who completed all the MOOC steps, but required payment of a fee.[35]

Participants using our website could take the tests in the manner of "progress testing" in which the same quiz was taken more than once. Progress testing directs study to objectives on questions missed and allows for achievement of a better score to reinforce learning. Such usage, as well as questions not answered, likely accounted for some of the wide range in scores observed for each test (Fig. A1). Voluntary testing is confounded by potential lack of participant motivation for compliance with goals of testing. Participants may not have had any association with or background knowledge of health sciences but merely curious about our website, or they could have taken the tests without reviewing module content.

Availability of testing may have educational value, particularly when barriers to access are reduced. A study involving 1701 medical students had random assignment to 2 groups: one took a formative progress test covering basic and clinical sciences with online access via a mobile device, while the other group took the test at the local testing center under usual examination conditions. There was no significant effect on the test score between the 2 groups, but students in the mobile group spent more time on the test, were less likely to quit taking the test, and were more likely to use the help of books or online resources.[36]

Access to formative testing aids self-directed learning. An online resource can be accessed 24/7, utilized as often as desired, and provided immediate feedback on performance. However, summative testing, taken more seriously, will yield higher scores. As an example, in the most recently completed Fall semester at the authors' medical school, formative test scores averaged 58% while summative test scores averaged 76%.

A study of formative assessment in a kidney pathology curriculum within a 3-week-long renal pathophysiology course deployed 5 online formative quizzes with 10 questions each. Quizzes were viewed 1487 times by up to 82.6% of 161 students. Usage was greatest the day before the final summative exam, with the total of 631 attempts (average 126 per quiz) and up to 57.1% of all students. The 17.4% of students who did not use the quizzes showed similar performance on the final exam for both quizzed and non-quizzed topics. Students using pathology quizzes also demonstrated similar performance for quizzed and non-quizzed topics, but they performed better than 'non-quizzers' on the final exam, for both quizzed and non-quizzed topics.[37]

Formative assessments can have value for learning with achievement. In a study of formative assessments in a physiology course, for all quiz models tested, a significant correlation between performance in quizzes and performance in the end-of-session examination was observed. Students who failed the end-of-session examination performed significantly worse in online quizzes than those who passed.[38] A prior study of student usage of web pages for feedback on performance in an objective structured clinical examination (OSCE) showed that students who passed all OSCE stations made the most use of the website, whereas students who just passed made least use, despite their risk of failing future assessments and having the most to gain from the feedback.[39]

Open access websites for learning and assessment can have value for participants in places with limited resources. One study of a web-based training and testing website offering education in urologic pathology showed that, just like social determinants of health predict access to more resources predicts better outcomes, so to pathologists in upper middle resource countries performed the best overall. However, the greatest improvement in diagnostic ability was achieved by participants in low resource countries.[40]

A project with some similarity to ours, but in a formal curriculum, involved development of cases in modules for medical students in clinical clerkships at a single academic institution. Students worked through clinical cases, making decisions regarding the ordering or interpretation of laboratory tests. Like our assessments, pre- and posttest questions were not identical, but all were mapped to a learning objective of a case module. After initial review of student time spent on modules, pre- and posttests were shortened from 10 questions to 5 questions each. Results showed posttest scores significantly higher than pretest scores for the 203 students participating.[41]

A prior study of urology residents preparing for an in-service examination with a self-assessment study program showed a modest increase in scores for a cohort utilizing an online educational program based on spacing effect principles, compared to a single bolus distribution format.[42] Our web-based approach offered participants a similar opportunity to space their utilization of the learning content and assessments.

A website offering a freely available web-based program to improve pathology residents' ability to Gleason grade prostate cancer on needle biopsy specimens was constructed similar to ours, with participants taking a pretest, then viewing a tutorial of images with diagnoses, then taking a posttest. In 2.5 months, 255 residents visited the website, averaging 3.4 hits per day, and 59% completed pre- and posttests. For those residents completing the tutorial significant improvement in grading was documented for 11 of 20 images, but significant improvements were noted in only 4 of 13 (31%) Gleason score 5 to 7 tumor images. A previous study of practicing pathologists using the same website improved grading of Gleason scores 5 to 7 tumors in almost 70% of cases.[43]

A study similar to ours captured self-identified demographic information on participants who had to register to create an account for access to a database of thin prep Pap smear cases.html. A total of 51 289 digital slides were reviewed by 918 different reviewers including cytotechnologists (81.5%), pathologists (15.5%), pathology residents (1.16%), and other types of reviewers (1.77%). Individual reviewers viewed between 1 and 320 cases and spent between 1 s and 8 days per review. Pathologists matched the reference diagnosis in 6363 cases (79.8%), and matched the diagnostic category in 7034 cases (88.2%). Biotechnological demonstrated a greater diagnostic match for each category as well for most of the individual Bethesda system interpretations compared to pathologists. This study demonstrated variability in user interaction and distractability, based upon the wide ranges of time documented reviewing a slide, which confounds attempts to analyze how users interact.[44]

Is the knowledge gained from educational efforts sustained over time? One study showed that the effectiveness of an educational program intervention in decreasing utilization of the prothrombin time determination by house staff physicians at a teaching hospital declined from 87% to 55% six months after the intervention.[45] We addressed this problem of retention, as do others, by providing a website for continuing access for reinforcement of learning. How frequently anonymous users via open access review such sites is difficult to document.

Fig.A2 illustrates the variety of participants across a spectrum from student to resident to practicing physician, which may be expected from general usage of a website. We were encouraged to observe the largest amount of usage by MD participants, as this was the target audience for the published curriculum upon which the objectives for learning modules and tests were derived. However, we were also encouraged to note participation by other health science students and professionals, as they play a role on health care teams, and increased understanding of aspects of health care diagnosis and treatment by all team members can potentially improve the function of the whole team.

Online education requires curriculum development. One approach to format is production of self-paced modules, with curriculum access initiated and self-directed by the learner. The potential reach is high from worldwide internet access.[46] We built upon a previously published curriculum and made use of a website with instructional and assessment technology already in place.

Employment of learning theories and concepts may improve the effectiveness of CAI for development of skills and knowledge. Interactive CAI may be more effective than CAI without interactivity. The deductive method (from data to diagnoses) may provide higher posttest results than the inductive method (from diagnoses and data to the rules of diagnostics). A study of students using a pedagogic format, offering educational support, showed more knowledge gain than students using a format attempting to model clinical reasoning or a problem-solving format, but they were less able to use this knowledge.[47] Another study showed users valued a learning module more when it was of shorter duration and aligned to curriculum topics, and 5 of 52 modules consistently attained high usage.[48]

Our website project and many others demonstrate one example of website development to support pathology education in ways previously described for e-learning: it is available anywhere at any time, providing personalized learning and pacing with an interactive and independent format in a cost-effective manner, but there is a need for self-motivation and time management skills.[49] Our resource, as well as many others intended for a wide audience with an interest in laboratory medicine education, is not tied to a single institutional curriculum, training program, location, or time frame. Our learning modules are based upon a published curriculum outline designed to support improvement in knowledge and application of laboratory testing, further informed by Choosing Wisely® recommendations for laboratory testing to support high value health care.[50] Other pathology websites likewise can be based upon shared expertise for educational value to participants.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Mercer University School of Medicine Summer Scholars Project with funds donated by Edward C. Klatt.

Appendix

Table A1
Test usage and scores.

Module test	Total entries	Mean score %	Completed entries	Mean score %	% Completion	Question score % Range
Pretest 1	2750	47.88	2300	54.75	83.64	29.50 to 73.03
Posttest 1	580	73.48	516	81.08	89.00	73.33 to 89.10
Pretest 2	1283	58.13	1038	68.13	80.90	51.17 to 80.48
Posttest 2	609	53.00	465	63.53	76.35	47.28 to 75.05
Pretest 3	879	53.11	725	53.04	82.48	52.34 to 56.47
Posttest 3	310	52.39	228	66.84	73.55	61.54 to 74.29
Pretest 4	947	53.54	781	61.95	82.47	39.83 to 77.41
Posttest 4	395	54.53	311	64.31	78.73	45.48 to 80.06
Pretest 5	612	53.14	496	62.7	81.05	35.40 to 83.37
Posttest 5	312	54.55	243	65.68	77.88	50.55 to 80.92
Totals	8677	55.38	7103	64.20	80.61	

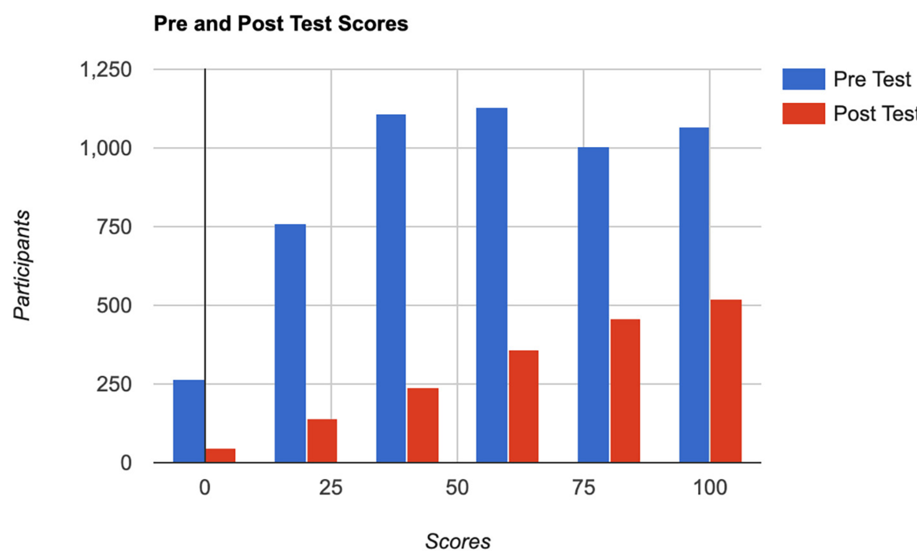

Fig. A1. Overall test usage and scoring improvement.

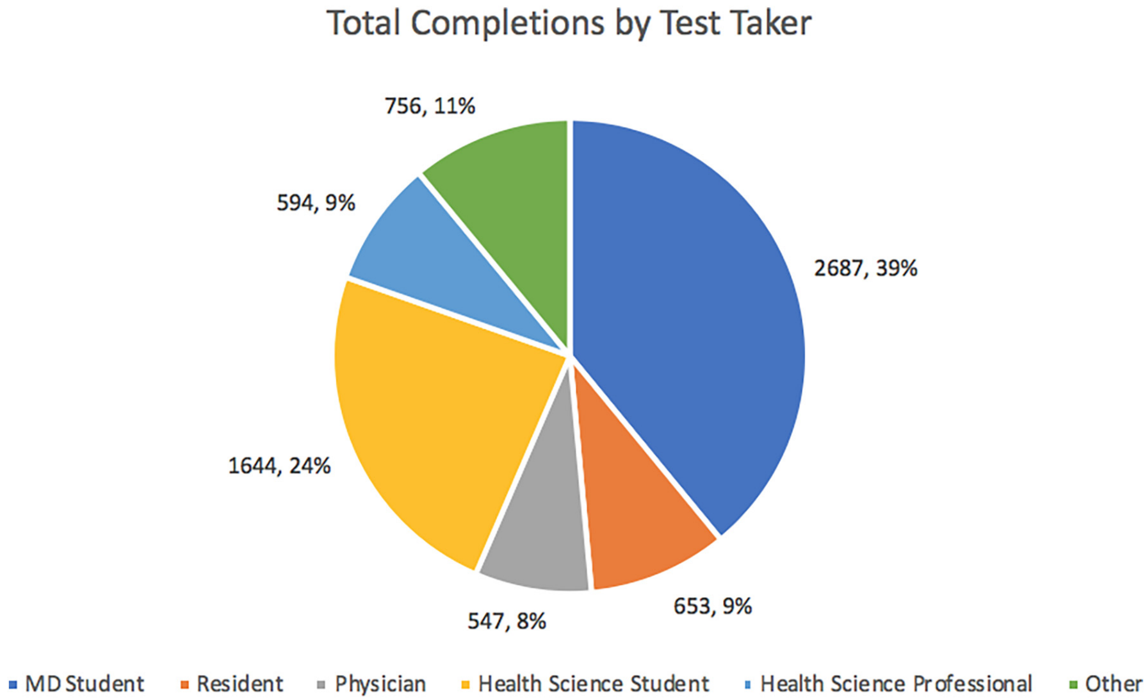

Fig. A2. Categories of participants by training and profession.

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