

Enhancing Pathology Knowledge for Biomedical Scientists: A Comprehensive Self-Paced Online Curriculum for Bridging Fundamental Concepts and Translational Applications

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Enhancing Pathology Knowledge for Biomedical Scientists: A Comprehensive Self-Paced Online Curriculum for Bridging Fundamental Concepts and Translational Applications

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Abstract

Background: Pathology is a cornerstone discipline in both clinical medicine and biomedical research, serving as a bridge between basic science discoveries and their translational applications. However, many biomedical scientists and healthcare professionals lack structured training in the fundamental principles of pathology. This gap can hinder their ability to interpret disease mechanisms, integrate pathology-based findings into their work, and collaborate effectively across disciplines. Addressing this unmet need through accessible, structured educational initiatives is essential to support professional development and foster interdisciplinary research.

Objective: Knowledge of pathology is integral to numerous healthcare- and research-disciplines, besides routine laboratory-medicine operations. Despite its importance, there remains a significant gap in structured educational programs designed to provide a fundamental understanding of the pathologic basis of disease, for an interdisciplinary body of research healthcare professionals. This lack of generalized pathology training may contribute to a broader knowledge deficit in its translational applications. To address this unmet educational need, we developed a distinctive pathology training course tailored to cater a broad array of scientists in basic- and translational science.

Methods: Twenty-nine participants from UT MD Anderson Cancer Center and the Texas Medical Center completed the "Fundamental Pathology for Basic Scientists: A Self-Paced Online Certificate Course" pilot. The course, comprising 24 instructional modules, was delivered over the span of 6 months in an online, asynchronous and readily-accessible CANVAS learning management format. The educational objectives for each module were organized around organ- and organ-system-specific content, aiming to 1) incorporate the pathological basis of diseases, 2) distinguish clinicopathologic correlations, and 3) recognize the impact of molecular- and translational pathology and associated state-of-the-art diagnostic technology. Participants were voluntarily surveyed both before- and after the course to assess its effectiveness.

Results: The pre-entry survey revealed that participants represented 16 academic departments (with widely varied training backgrounds, career-stages and job descriptions within the biomedical research enterprise), with 76% reporting no prior basic pathology training. The exit survey highlighted positive feedback on the course structure, instructors, delivery method, lecture content. At least 89% of learners concurred that each of the 24 modules had delivered its learning objectives. 94% of learners concurred that the course enriched their understanding of basic pathology. Additionally, 79% of participants reported applying/being able to apply what they had learned to their current roles, and 94% of post-course survey respondents confirmed longer-term benefits 1 year after program completion (increased confidence in addressing projects involving pathology).

Conclusions: The initial outcomes of this pilot course suggest that the asynchronous delivery method was well-suited to participants' workloads, and that the content was valuable for basic- and translational-scientists from varied training backgrounds

seeking to deepen their understanding of fundamental pathology in the context of biomedical research. This work establishes a model for scalable, technology-enabled pathology training adaptable to diverse learners within healthcare research centers.

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ABSTRACT

PURPOSE: Knowledge of pathology is integral to numerous healthcare- and research-disciplines, besides routine laboratory-medicine operations. Despite its importance, there remains a significant gap in structured educational programs designed to provide a fundamental understanding of the pathologic basis of disease, for an interdisciplinary body of research healthcare professionals. This lack of generalized pathology training may contribute to a broader knowledge deficit in its translational applications. To address this unmet educational need, we developed a distinctive pathology training course tailored to cater a broad array of scientists in basic- and translational science. **METHODS:** Twenty-nine participants from UT MD Anderson Cancer Center and the Texas Medical Center completed the *"Fundamental Pathology for Basic Scientists: A Self-Paced Online Certificate Course"* pilot. The course, comprising 24 instructional modules, was delivered over the span of 6 months in an online, asynchronous and readily-accessible CANVAS learning management format. The educational objectives for each module were organized around organ- and organ-system-specific content, aiming to 1) incorporate the pathological basis of diseases, 2) distinguish clinicopathologic correlations, and 3) recognize the impact of molecular- and translational pathology and associated state-of-the-art diagnostic technology. Participants were voluntarily surveyed both before- and after the course to assess its effectiveness. **RESULTS:** The pre-entry survey revealed that participants represented 16 academic departments (with widely varied training backgrounds, career-stages and job descriptions within the biomedical research enterprise), with 76% reporting no prior basic pathology training. The exit survey highlighted positive feedback on the course structure, instructors, delivery method, lecture content. At least 89% of learners concurred that each of the 24 modules had delivered its learning objectives. 94% of learners concurred that the course enriched their understanding of basic pathology. Additionally, 79% of participants reported applying/being able to apply what they had learned to their current roles, and 94% of post-course survey respondents confirmed longer-term benefits 1 year after program completion (increased confidence in addressing projects involving pathology). **CONCLUSIONS:** The initial outcomes of this pilot course suggest that the asynchronous delivery method was well-suited to participants' workloads, and that the content was valuable for basic- and translational-scientists from varied training backgrounds seeking to deepen their understanding of fundamental pathology in the context of biomedical research. This work establishes a model for scalable, technology-enabled pathology training adaptable to diverse learners within healthcare research centers.

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INTRODUCTION

In biomedical research, it is essential for basic science scholars, graduate students and postdoctoral fellows to not only master their research-specific disciplines, but also stay updated with advancements in interdisciplinary related fields that impact their mainstream research focus. One such interdisciplinary area is pathology, which plays a critical role in bridging the gap between basic research and its clinical applications. A broad understanding of this field is an indispensable asset for basic scientists and healthcare professionals alike. Insights into the pathological basis of disease are vital for uncovering mechanisms of disease progression and identifying potential therapeutic targets in the research-lab. Similarly, professionals in laboratory-medicine rely on pathology to diagnose and monitor diseases, interpret lab results, and contribute effectively to patient care. Although the need to build/update knowledge and skills in pathology is eminent for workers in healthcare research centers, many unfortunately either find themselves distanced from foundational pathology concepts over time, or lack exposure to the latest developments in translational pathology and emerging technologies[1-3]. In addition to these challenges, are a litany of unmet educational needs and pre-existing/unsolved issues plaguing training programs in pathology, spanning decades from the 1980s to the present day: 1) limited resources for training research scientists in pathology, balancing emphasis on molecular vs. general pathology topics, 2) lack of attraction to pathology as a dedicated career track for postgraduate students, and 3) attrition of trained pathologists (limited availability of qualified instructors)[4-8]. There is also a significant gap in the availability of local pathology courses designed for a broader range of professionals who have not pursued “formal” pathology training or work outside of traditional academic pathways, yet require a solid foundation in this field to enhance their everyday work. Well-recognized training program scholars, however, highlight that regardless of the job type, 70% of learning that directly impacts job performance occurs *on* the job, suggesting the dire need for locally accessible pathology learning courses catering to the career needs of an expansive learner population in healthcare research centers[9].

To directly address this educational gap, we engaged in the intentional development and delivery of a self-paced learning course to serve a broad breadth of learners in the healthcare workplace - ranging from graduate students and postdoctoral fellows in translational research, to research assistants, technicians, basic scientists, histotechnologists, laboratory managers, quality assurance specialists, to data specialists, as well as research faculty. The “Fundamental Pathology for Basic Scientists” course was developed as part of the ITERT (Interdisciplinary Translational Education and Research Training) Core at the University of Texas MD Anderson Cancer Center (MD Anderson), a platform dedicated to advancing the educational and professional development of the next generation of leaders in translational research[10, 11], in partnership with the department of Education Development & Innovation (EDI).

The curriculum was tailored to provide participants with a comprehensive understanding of *traditional* pathology concepts (*Robbins & Kumar Basic Pathology, Eleventh Edition*, the international gold-standard text) while integrating instruction on *modern innovations in molecular pathology and methodologies* that are pivotal to new-age translational research (instructors sharing relevant pathology research using state-of-the-art methodologies and instrumentation). The course offered a unique opportunity for participants to deepen their understanding of pathology in a research context, revisit core pathology principles, acquire updated knowledge in translational pathology, and also importantly, engage with interdisciplinary workforce professionals and network with a constellation of trained pathology mentors and instructors. This study describes the initial training outcomes of this pilot educational course.

METHODS

Course objectives: The primary goals for this course were to (1) address the non-availability of workplace training in fundamental pathology (that is traditionally limited to degree-awarding academic programs) by creating a non-degree certificate course open to learners from different disciplines in biomedical research, (2) provide a structured learning rubric for understanding the pathological basis of disease in an organ-organ system format, (3) design flexible self-paced/asynchronous learning modules to serve full-time employees in the healthcare research enterprise, and (4) develop a support network (peer- and tiered-mentoring) for non-pathology healthcare professionals who indirectly interface with the pathology-domain.

Course participants: Recruitment targeted researchers, staff scientists, and health professionals from across the Texas Medical Center in Houston, Texas, interested in completing a structured course on fundamental pathology for their professional development. The 29 individuals who completed all modules of the course encompassed 10 different professional roles across 16 different academic department affiliations enrolled in the course with the largest single-career stage represented (27.6%) being research postdoctoral fellows (**Supplementary Table 1**). 90% of the participants were from MD Anderson and 10% from UT Health Houston.

A learner analysis was conducted to gain understanding of the participants' training backgrounds and learning objectives. This information was captured in a pre-course survey administered before participants began course-work. Following best practices for conducting a learner analysis, 5 essential concepts were adhered to, in accordance with recommendations by Stefaniak[12]:

1. General characteristics
2. Prior pathology knowledge and prerequisite skills of participants
3. Predispositions pertaining to the topic of pathology
4. Attitude and motivation toward training
5. Characteristics of the group as a whole

This early analysis allowed for a comprehensive snapshot of learner demographics in terms of academic career-stage, background experiences in pathology and instructional modules needing content tailoring.

Course design, curriculum and delivery: Three key factors were taken into consideration when designing this course: (1) the broad target audience of basic scientists from various departments and academic career stages, with diverse training backgrounds and work roles, (2) the need for participants to complete this course alongside their full-time/regular work duties, and (3) course accessibility for participants from across the Texas Medical Center in Houston, Texas. The CANVAS Learning Management System (LMS) was selected for the asynchronous delivery of course materials (**Figure 1A**), which consisted of lecture videos, presentation files, supplementary reading material (research publications, techniques/methods aids) and quizzes.

Twenty-four learning modules were organized, each focusing on topics of interconnecting physiopathology contents and clinicopathologic correlations with specific organ systems (**Figure 1B**). Traditional pathology topics were based on *Robbins & Kumar Basic Pathology, Eleventh Edition*, the international gold-standard text for pathological disease[13], and information from this book guided the selection of content for the majority of the modules (Modules 1-22). While we endeavored to adhere to the sequencing of chapters as in this well-established teaching resource that is recognized in the field, each lecture however, was tailored to our specific audience with varying levels of pathology knowledge, and the course also included two additional modules covering molecular pathology and translational pathology, not addressed in[13]. Module 23 on molecular pathology covered the definition of molecular pathology, molecular basis of disease, molecular pathology tools, diagnostic molecular pathology, and tumor molecular profiling. Module 24 on translational pathology covered introduction to translational pathology, -omics research, genomics,

metabolomics, and other omics for target identification and validation, biomarkers in oncology, genetics and molecular biomarkers, and artificial intelligence to improve diagnostic and prognostic efficacy. Furthermore, we incorporated Elsevier's *Evolve Resources for the Instructor-Led Course Robbins & Kumar Basic Pathology, Eleventh Edition*[14], which allowed us to tailor the content and learning experience to the unique needs of each participant, ensuring broad accessibility and learner engagement. Additionally, instructors enhanced each module by sharing relevant recent literature to reveal the incorporation and utility of modern methodologies and instrumentation for pathology work.

This 24-module pilot course was offered over a span of six months. One module was released sequentially in CANVAS each week, and included an estimated one hour of recorded video instruction on the topic, supplemented with relevant reading material from current literature. Participants were allowed to complete the module at their convenience, which provided considerable flexibility in accommodating their coursework into their ongoing work schedules and job responsibilities. Each module was created and taught by subject-matter experts from MD Anderson, and lecturers offered virtual office hours after every four modules to promote inquiry and interaction, and follow-up on any additional learning resources the participants needed.

The professional roles of the instructors spanned the range from early-career assistant professors to associate professors, research scientists and clinical pathology fellows to research postdoctoral fellows. All instructors were members of either the Pathology or Translational Molecular Pathology departments at MD Anderson, and had received formal pathology training in the United States or internationally. Lecturers constructed a multiple-choice style quiz of ten questions for each module, and learners were allowed multiple attempts to complete the quiz with a benchmark score of 80% for passing each module. The 29 participants completed all 24 modules, and were issued a certificate of completion at the end of the 6-month pilot course.

Course evaluation: Three surveys were issued to obtain pertinent insight. All surveys were conducted using the institutional Qualtrics management software. The first survey was a pre-entry questionnaire administered before the course, intended to collect background information from participants on departmental affiliation, prior training in basic pathology, and application of pathology reports/basic pathology in their current job role/s.

The second survey for evaluation was the exit survey, administered to each participant after completing all 24 course modules enroute to gaining their course certificate. Aligned with a prominent, evidence-based practice for evaluating training programs, the exit survey was framed according to the Kirkpatrick Four-Level Evaluation Model[9, 15] that has persisted as a gold-standard to the present day. The survey was subdivided to flow through key evaluation points on course structure, lecture delivery, module content, learning and knowledge application, and concluded with a free-response section for additional feedback. Each of the four Kirkpatrick levels (*ie.*, 1: reaction, 2: learning, 3: behavior, 4: results) were sequentially featured (**Table 1**).

Relevance to Kirkpatrick Level	Topics surveyed
1	Duration of the course, learning objectives of each module and organization of course content, utility of the virtual office hours, delivery format, course balance with work duties, format and delivery of quizzes
2	Pathology-specific knowledge and skills gained, quizzes, confidence in applying their newly learned skills
3	Relevance to their current job role/s and/or career-development goals, enhancement of current work duties
4	Specialized pathology course interest, long-term value

Table 1. Topics surveyed for course evaluation and their alignment with the Kirkpatrick model of training program evaluation.

The majority of the exit survey items were geared towards Kirkpatrick levels 1 and 2 as these are areas of immediate and high interest to the launch of a new training program. This evaluation was essential to fine-tune and tailor the modules in real-time, for optimal learning and instructional design. We also assessed our evaluation against a well-established interdisciplinary, problem-centered approach to using educational technology for learning design and instructional systems development[16]. Spector posed five levels of evaluation on the application of educational technology for instructional design when constructing a course or program in any discipline. Applying the Spector scale to the evaluation of this pilot course, our key metrics are shown in **Table 2**.

Specto r Level	Criteria for good learning and instruction	Supporting course statistic
1	Learning goals and objectives are met (formative and summative)	Course requirement ensured a minimum of 80% passing score per module (all students passed each module); at least 89% of participants confirmed that the course modules had met their stated learning objectives
2	Learning setting is useful, and content aligned with stated objectives	At least 89% of participants confirmed that the course delivery format was favorable; at least 90% confirmed the course duration was appropriate and that the distribution of instructional content in the models was favorable and aligned with the stated objectives
3	Overall course experience is satisfactory	94% of participants confirmed they would recommend this course to a colleague
4	Program is sustainable	Future direction to probe (long-term course iteration evaluation is necessary to determine course sustainability)
5	No harm is done	94% of post course survey respondents concurred that their self-knowledge in fundamental pathology has increased because of participating in this course. Future direction to probe long-term technological impact (planned 3-year post-course participant follow-up)

Table 2. Course evaluation criteria breakdown in alignment with the Spector scale for instructional program evaluation

The final survey was conducted 1 year after program-completion, to assess longer-term impact of the course on participants' career- and professional development, teaching abilities and sustained confidence in basic pathology knowledge and skills.

RESULTS

Pre-Course survey: Of the 29 participants who completed the course, the majority (96.6%, n=28), had previous biology training, and 72.4% (n=21) had prior histology knowledge. Interestingly, while 79.3% (n=23) of participants either used pathology reports or basic pathology concepts in daily work activities, only 24.1% (n=7) had previously received formal pathology training. Trainees (graduate students and postdoctoral fellows) only accounted for 31% (n=9) of the participants, while the majority (69%, n=20) were professionals in formal work capacities within the academic centers. A more detailed profile of the learners is provided in **Supplementary Table 1**.

Course exit survey (immediate/near-term training impact): All 29 course participants who completed the course, completed the exit survey also. A Likert scale was employed to assess participants' opinions on course structure, course content, and course lectures (**Figure 2**). 93% of participants concurred (agreed/strongly agreed) that the course duration and distribution of the course in 24 instructional modules was appropriate. When questioned about live instruction office hours, 86% of participants concurred that it was adequate and appropriately distributed. Ninety percent of participants considered the course delivery format using lecture videos *via* CANVAS to be favorable, and 80% reported being able to effectively manage the course requirements alongside their primary work.

The second section of the questionnaire surveyed participants' opinions on course content. For each module, two statements were explored: "I feel that the learning modules met the stated learning objectives," (*learning objectives met*) and "The lecturers of the course effectively covered the learning objectives in their lecture videos" (*lecturers/videos covered objectives effectively*). The detailed assessments are shown in **Supplementary Table 2**. Overall, the feedback for both queries was strongly positive, with at least 89% of participants concurring (agreeing/strongly agreeing) favorably with both statements for each of the 24 modules, underscoring the high quality of the instructional content, the superior teaching abilities of the instructors and the strong alignment of the presented content with the stated learning objectives (**Figure 3**).

The third section of the exit survey focused on statements related to comprehension and standards of the course lectures as well as ability to address the quiz questions at module completion (**Figure 4**). Eighty-three percent of participants concurred (agreed/strongly agreed) that the lectures were easy to comprehend, 94% concurred that the lectures covered the basic pathology of the stated topics and matched currently accepted standards in the field. Eighty-three percent concurred (agreed/strongly agreed) that the breadth and depth of the quiz questions aligned with the content covered in the lecture videos.

The final section of exit survey assessed the overall impact of the course on participants' careers and the potential application of what they learned in their current roles (**Figure 5**). Seventy-nine percent of participants concurred (agreed/strongly agreed) that they have either already applied or will be able to directly apply the content learned from this course to their current roles. 73% concurred (agreed/strongly agreed) that participation in this course made them feel more confident either in their current role or in approaching future job search along their career trajectory. 94% concurred (agreed/strongly agreed) that participation in the course directly enhanced their basic pathology knowledge. Further, 94% percent of participants also concurred that they would recommend this course to a colleague. Notably, 90% of participants concurred that they would like to return to participate in a more specialized pathology course (advanced topics in pathology - such as neuropathology, advanced tissue imaging and analysis techniques, animal disease model pathology, histology staining and processing techniques, histology interpretation, hematopathology, and

cytopathology were suggested as content for future specialized course options), highlighting the positive impact of the pilot training course.

We also received free-response feedback from sixty-six percent of participants, regarding potential opportunities for course improvements in future iterations. Suggestions included the provision of additional relevant journal articles, the creation of a discussion board for learners to engage in conversations around pathology-related discussion prompts, providing more detailed explanations for images, varying the types of questions in quizzes, and collaborative activities among learners.

Post-course survey (longer -term impact on career- and professional development): Of the 29 participants who graduated from the pilot course, 55% (n=16/29) completed post-course survey responses, a year after program graduation. 50% of the respondents (8/16) had had a job change within the past year, and 81% (13/16) concurred that their current job role/s involved pathology (data not shown). 94% of respondents concurred (agreed/strongly agreed) that they felt more confident in participating in discussions concerning fundamental pathology topics at work (**Figure 6**). 94% of respondents also concurred that their self-knowledge in fundamental pathology has increased because of participating in this course (**Figure 6**). Feedback in the form of free responses indicated that the course helped learners identify and differentiate the distinct cell types within tissues, better understand mechanisms of resistance, better understand research results, quality assurance, better understand microscopic histology techniques, immunohistochemistry data, disease processes at a cellular level, as well as better understand normal tissue structure that has helped in recognizing tissue abnormalities. Learners also stated that this course made them more comfortable with pathology, made it easier to connect scientific concepts to real-world applications, and helped open career opportunities.

Further, 81% of respondents concurred that they were better able to assist colleagues with inquiries or projects involving pathology and 75% agreed/strongly agreed that they were even better able to train students or peers because of participating in this course (**Figure 6**). Free response feedback also opened up more avenues for course improvement suggesting the need for better clarity in image descriptions within the video lectures.

DISCUSSION

The lack of accessible, structured learning opportunities in fundamental pathology creates a significant knowledge deficit that can limit career advancement for basic and translational scientists within the healthcare research enterprise. Furthermore, the rapid pace of advancements in biomedical research emphasizes the need for continuing education in pathology to ensure that professionals stay abreast of the latest developments. It is also imperative for such workplace training initiatives to embrace and integrate digital tools and virtual learning to solve access issues in the setting of the post-COVID-19 pandemic[17].

The *Fundamental Pathology for Basic Scientists* course was developed to fill this knowledge gap using local institutional resources, attracting participants from 16 different academic departments, and representing 10 distinct job roles within the biomedical research enterprise at Texas Medical Center, ranging from early-career scientists to more established professionals, with the majority (76% of participants) lacking formal training in pathology (**Supplementary Table 1**). The wide-ranging diversity of enrollees underscores the broad relevance of pathology knowledge across various career stages and disciplines. It also reflects the interdisciplinary nature of modern biomedical research, where a shared understanding of pathology can facilitate more effective collaboration and innovation. The positive feedback from participants, along with the wide range of departments and career stages represented, highlights the unmet demand for pathology education tailored to the needs of working professionals. This demand suggests that similar courses could be highly beneficial if made more widely available, particularly in online, self-paced formats that accommodate the busy schedules of professionals across different fields. Our study confirms and extends previous reports in literature [18, 19], showing that readily-accessible (such as locally-curated) educational resources would help close the knowledge gap in pathology and empower a broad audience of scientists and healthcare professionals to apply this critical education in their respective domains, and also facilitate advanced/inter-disciplinary career opportunities within broader biomedical research disciplines (eg., teaching) (**Figures 5, 6**).

The course's comprehensive curriculum, covering an extensive range of basic pathology topics, was one of its key strengths, with the benefits continuing to grow for participants even after a year of course completion (**Figures 3, 6**). The observation that at least 89% of participants uniformly concurred that each of the 24 modules had met its stated learning objectives confirms the appropriateness of the instructional content. The evaluation method for course content primarily involved quizzes integrated into each learning module. These quizzes served as both an assessment tool and a reinforcement strategy, ensuring that participants engaged with and retained key concepts. This approach aligns with educational research that supports the use of frequent, low-stakes quizzes to enhance knowledge retention and promote active learning[20, 21]. Participants responded positively to this form of assessment, appreciating the immediate feedback and the alignment of quizzes with the course content.

The observation that 93% of post-course survey respondents felt this course significantly enhanced their knowledge and skills and further made them more confident in approaching projects involving pathology or even engaging in pathology-related discussion (**Figure 6**), demonstrates longer-term impact of this course and also its practical value for application across a wide spectrum of biomedical branches. The high level of participant engagement highlights the course's ability to meet the diverse needs of a varied audience and reinforces its importance as a vital and readily-accessible resource for professionals seeking to deepen their understanding of pathology in the context of their work.

Opportunities for program enhancement in future iterations: The course, delivered over six months with 24 weekly modules, was designed to be flexible through an asynchronous format, allowing participants to integrate learning with their ongoing professional duties. While the course was effective in meeting its educational objectives, feedback indicated that managing the course workload alongside professional responsibilities remained a significant challenge for 20% of the

participants, suggesting that the course structure could benefit from further refinement. Several strategies could improve the course experience in future iterations: Extending the overall course timeline to eight or ten months could provide participants with more time to complete each module, making it easier to balance their educational pursuits with their professional duties. Modifying the module release schedule, by releasing modules biweekly or in clusters, instead of weekly, would offer participants greater time and flexibility in managing their schedules. Additionally, incorporating optional review periods or breaks between certain modules could serve as catch-up periods, reducing the pressure of keeping up with a weekly release schedule. Providing time management resources or strategies, such as workshops or tips on integrating learning with daily routines, could further help participants balance the course with their work. Regular feedback from participants could also be used to make real-time adjustments to the schedule or workload, ensuring the course remains manageable for all participants.

Some participants suggested incorporating more diverse question types, such as case-based questions or scenario analysis, to better simulate real-world applications of pathology knowledge. Future iterations of the course will expand the quiz format to include a broader range of question types and consider adaptive quizzes that adjust in difficulty based on participants' responses.

Further, while the course's overall curriculum was well received, some participants expressed a desire for more specialized topics, particularly in emerging areas of translational pathology. This could include advanced diagnostic techniques or deeper explorations of subspecialties like neuropathology or hematopathology. There were also suggestions for more interactive elements, such as case-study discussions, or group projects, to enhance engagement and deepen exploration of the material. Incorporating occasional synchronous sessions, despite the overall asynchronous format, could also provide a more dynamic learning experience. Lastly, although virtual group office hours were offered, additional virtual availability with instructors on a one-on-one basis at the request of the participants seemed necessary to address inquiries or other ongoing course needs. Future iterations will seek to incorporate these suggestions and improvements into the curriculum.

Conclusions: The *Fundamental Pathology for Basic Scientists* course represents a local institution-based immersive learning tool to effectively address a critical educational gap in pathology for basic- and translational scientists. While the pilot course was successful in achieving its training goals, multiple opportunities for course enhancement were identified from participant feedback. Future iterations of the course will consider extending the timeline, offering more specialized content, enhancing the image descriptions, and increasing interactive elements to enhance the learning experience. Regularly soliciting participant and instructor feedback will be crucial in continuously improving the course and ensuring it remains a valuable resource for the next generation of basic scientists and healthcare professionals.

FIGURE LEGENDS

Figure 1. *Fundamental Pathology for Basic Scientists: Course structure highlights (A) and Curriculum overview (B).* Shown in B are the 24 instructional modules for this course (image rendered using BioRender).

Figure 2. *Fundamental Pathology for Basic Scientists: Data on participants' perceptions of course structure.* A Likert scale assessment of agreement with five statements evaluating the course duration, distribution of modules, delivery format, live instruction availability, and participant ability to manage courseload (n=29).

Figure 3. *Fundamental Pathology for Basic Scientists: Data on participants' perceptions of course effectiveness.* A Likert scale assessment of agreement with two statements evaluating achievement of learning objectives and effectiveness of instruction for each individual course module. At least 89% of learners agreed/strongly agreed that the lecturers and videos covered the stated objectives effectively and that the learning objectives were met, in each of the 24 modules (n=29).

Figure 4. *Fundamental Pathology for Basic Scientists: Data on participants' perceptions of course lectures.* A Likert scale assessment of agreement with three statements evaluating course comprehension, standards and adequacy, and alignment of course assessment quizzes with instructional content (n=29).

Figure 5. *Fundamental Pathology for Basic Scientists: Data on participants' perceptions of near-term impact of course on professional development and career support.* A Likert scale assessment of agreement with five statements evaluating course applicability to current career stage, confidence in job search, knowledge and skill development, and sustained interest in returning for an advanced course in pathology (n=29).

Figure 6. *Fundamental Pathology for Basic Scientists: Data on longer-term (One year post-program completion) impact of course on participants' pathology knowledge and teaching skills.* A Likert scale assessment of agreement with four statements evaluating longer-term utility of learned pathology knowledge and skills (n=16).

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DECLARATIONS

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Competing interests: The authors declare that they have no competing interests.

Data availability: The (deidentified) cohort dataset used and analyzed during the current study are available from the corresponding author/s upon reasonable request for non-commercial academic purposes.

Authors contributions: JS and LCC wrote the primary manuscript and analyzed the data. RS and MGR conceptualized the course and curriculum. JS, LCC, IW, RS and MGR designed the course structure. JS and LCC prepared and implemented the surveys. JS, LCC, DPF, MLS, IIW, RS and MGR performed data review, proofreading, writing and editing the manuscript. All authors have read and agreed to the publishable version of the manuscript.

Ethics approval: This study was reviewed and approved by the Institutional Review Board (IRB) at the University of Texas MD Anderson Cancer Center (OHRP IRB Registration Number: IRB00000121; Reference ID# 2024-1381).

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Supplementary Files

Multimedia Appendixes

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