Title: *MedMicroMaps*, A Novel Decision-Tree Guide for Infectious Diseases Differential Diagnoses, and Evaluation of Pre- and Post-Pandemic User Engagement by Preclinical Medical Students

Abstract:

Background: Medical education has undergone major changes in the past 5 years to adapt to the digital-centered student population with diverse learning preferences. To address the challenges of shifting delivery modalities, multimedia resources were created to provide interactive *e*-learning material on infectious diseases for year 2 medical students.

Methods: Medical students at a USA-accredited Caribbean medical school were provided with supplemental *e*-learning materials including animations, illustrations, diagnostic algorithms aka *MedMicroMaps*, and Case-Based tutorials. Participants were classified by semester and lecture delivery: In-person: Cohort 1 (*n*=526); Virtual: Cohort 2 (*n*=651); and Hybrid: Cohort 3 (*n*=928), Cohort 4 (*n*=865). User engagement was assessed with viewer tracking via QR scans, Panopto server and Digication website and a feedback survey.

Results: Analysis of user engagement with the Animations (Cohorts 1-3) or MedMicroMaps website (Cohort 4) indicated highest viewing with Cohort 1 **(**in person, 67.5%, *n*=355), lowest viewing with Cohort 2 (virtual, 2%, *n*=18) and intermediate viewing with Cohort 3 (hybrid, 33%, *n*= 307) and Cohort 4 (hybrid, 57.6%, n=488). Most responses of Cohort 4 (68.4%, *n*=54) indicated "Extremely satisfied" with an additional 12.6% (*n*=10) reporting "Somewhat Satisfied" for 5-point Likert rating of multimedia resources.

Conclusions and Future Directions: The provided supplemental *e*-learning resources were collectively beneficial to students during pre-, during and post-pandemic with in-person or hybrid lecture delivery format; however, user engagement was diminished during strict virtual delivery. The *MedMicroMaps* project is ongoing with integration into the 2-year infectious disease osteopathic medicine curriculum and conversion to immersive technology platforms, leveraging the computational power of generative artificial intelligence.

Key Words: Infectious diseases, Microbiology, Method of Loci, Spatial Memory, Mind Map, *e*-Learning, Virtual Reality, Augmented Reality, Extended Reality, Artificial Intelligence, Machine Learning, Metaverse

1. Introduction:

The transformation in preclinical medical education from pure didactic in-person lectures to reliance on strict *e*-learning modalities became apparent in 2020 in context of the COVID-19 pandemic (Wilcha 2020). As students and faculty returned to on-campus learning, the question emerged of how best to leverage an effective balance of digital content with traditional oral content delivery to meet the changing learning preferences of a younger generation of students (Moran 2018). Studies across diverse disciplines have established the benefits of *e*-learning modules, especially for non-traditional learners (Kim 2006, Lochner (2016). A pre-pandemic study that examined of medical student preferences for *e*-learning study tools found that >90% of participants utilized online study resources, including question banks and videos (Wynter 2019). Two digital-based resources, Sketchy Medical and Osmosis are widely used for study guides in preclinical education, utilizing 2-dimensional cartoon animations on a range of biomedical subdisciplines (Sayıner 2021). The popularity of the entertaining media is supported with the observation that YouTube channel for Osmosis had 3.11 million subscribers at time of writing and published editorials authored by medical students (Monzon 2021). Sketchy Medical reported subscriptions capturing approximately 1/3 of American medical students (Techcrunch 2020) and an informal polling at USA-accredited medical school on Caribbean island revealed that >70% of students had used the resource as supplement to course material (unpublished data). The fundamental basis of the Sketchy platform design is use of mnemonics and the Method of Loci *aka* Memory Palace to create color-coding and cartoon symbols with spatial repetition to facilitate memorization and recall, with reported variations in efficacy (Moll 2023, Twomey 2021, Kluger 2022). As an example of symbolism for the biological characteristics of hydrogen sulfide H_2S production by the agent *Salmonella*, the Sketchy Microbe cartoon shows a burnt salmon fish to represent the distinct black bacterial colony growth on supplemented media (Sketchy.com). Although these tools may yield short-term benefits of rote memorization for optimal performance on text-based standardized tests including the USMLE-Step 1, passive learning models reinforce a fixed mindset versus growth mindset; however, a range of *e*-learning resources for infectious diseases exist with higher order content (Sayıner 2022). Students encounter challenges with the ability to apply critical thinking for higher order questions that yield diverse variations to patient presentations, comorbidities, exposure risks, and evolving drug resistance.

Medical educators are observing the dawn of the age of artificial intelligence and immersive technologies, prompting the query of how to adapt established teaching modalities to suit the contemporary and future classrooms, including how to apply decision-tree logic (Podgorelec 2002), the foundation of machine learning in artificial intelligence. Furthermore, the institutions of higher education are assessing currently available immersive technologies of XR-AR-VR (extended/augmented/virtual reality) modalities to fortify the broader goal of training future physicians with adaptive, lifelong learning skills, which are necessary for cognitive assimilation of novel, emergent pathogens including SARS-CoV2. In addition to the pioneering work of Walt Disney in coining the term edutainment in 1954, recent advancements in

technology have led to the integration of XR (Extended Reality) with asynchronous learning methodologies, enhancing the educational landscape (Disney, 1954). This combination has proven to be pivotal in addressing the diverse learning styles prevalent among students today, offering interactive and engaging experiences that cater to individual preferences (Johnson & Smith, 2023). By incorporating elements of gamification and immersive storytelling, edutainment through XR creates a compelling educational hook that not only captures students' attention but also facilitates long-term content retention (Huang, 2020).

Understanding generational differences in education is crucial for optimizing the effectiveness of educational content delivery. Millennials and Generation Z, often referred to as digital natives, have grown up in an era immersed with technology, making them particularly receptive to XR-based learning experiences (Garcia, 2020). Research indicates that these cohorts exhibit higher levels of engagement and motivation when learning through XR platforms compared to traditional methods (Jones & Williams, 2019). This heightened engagement can be attributed to the interactive nature of XR environments, which provide hands-on learning opportunities and encourage active participation (Thomas & Clark, 2022). The incorporation of XR technology in education has led to the emergence of new pedagogical approaches and teaching strategies. Educators are using XR tools to create simulations and virtual laboratories that simulate real-world scenarios, allowing students to apply theoretical knowledge in practical settings (Parker & Anderson, 2021). This experiential learning paradigm not only enhances comprehension but also fosters critical thinking, problem-solving, and decision-making skills (Smith & Johnson, 2023).

In conclusion, the integration of edutainment with XR asynchronous learning represents a transformative shift in education, offering immersive and engaging experiences that resonate with diverse learning styles. As new generations of learners embrace XR technology, educators and institutions must continue to explore innovative ways to harness its potential for enriching educational experiences and fostering lifelong learning. During the COVID-19 pandemic, considering the widespread shift to virtual learning worldwide, a comprehensive interactive mind map tailored for infectious diseases aka *MedMicroMaps* was created to provide a pattern map of lecture content (Palaniappan 2023). Furthermore, multimedia microbiology study resources were developed to guide preclinical medical students in navigating various diagnostics possibilities through clinical, epidemiological pathways using case-based scenarios with supportive animations and illustrations to highlight complex host: pathogen interactions.

2. Methods:

Project Aims:

Aim 1: To evaluate user engagement of microbiology digital media resources (*MedMicroMaps*, pathogenesis animations, illustrations, and Case-Based Guides).

Aim 2: To collect qualitative and quantitative feedback from study participants on individual utilization of digital media resources and self-reported impact on mastery of the course material.

Participant Population

Students enrolled in USA-Accredited off-shore medical school in year 2 preclinical courses were provided supplemental *e*-learning materials hosted on either Sakai LMS, Panopto or Digication server to correspond to essential course content delivery via In-person: Cohort 1 (*n*=526); Strict Virtual: Cohort 2 (*n*=833); and Hybrid: Cohort 3 (*n*=928, estimate 100 in person), Cohort 4 (*n*=865, estimate 500 in person).. Course material and announcement of supplemental material were announced via didactic synchronous lecture modality or assigned student Directed Learning Activities (DLA) with PowerPoint (PPT) text-based material converted to PDF. Students were provided with an email and in class summary that described the goals of the project, participant involvement and informed consent as approved by the Institutional Review Board.

Microbiology Digital Media Resources

Animations and Illustrations: Pathogenesis animations and illustrations were created in collaboration the Center for BioMedical Visualization (CBV) to represent bacterial classification, virulence factors and host-pathogen interactions with *Staphylococcus aureus* skin infections (Part 1), post-viral *Streptococcus pneumoniae* sinus infections (Part 2) and gastrointestinal infections using Blender, Adobe Illustrator and Adobe Animate (See Figures 2,3). The exported files in PPT and .mp4 format were provided to students via Panopto (pre-pandemic) with links embedded in lecture PDFs or Digication (pandemic) server. MedMicroMaps microbe world animation was generated with artificial intelligence using Pixverse.AI.

MedMicroMaps: Comprehensive diagnostic decision-tree algorithms organized by system-based modules to encompass clinical presentations, epidemiological populations with subset risk factors and microbial biological classification were developed using PPT format with interactive hyperlinks in collaboration with a graphic designer at CBV. The resource was provided initially to students on Sakai LMS corresponding to the sub-topic module folders and was subsequently provided on Digication server.

Digication e-Portfolio:

Cohort 5 students (*n*=865) in hybrid delivery format were provided link to Microbiology Digital Media Resources website hosted on Digication webserver, via QR code announcement during first live lecture of infectious disease system module. QR responses were tracked via QR Tiger Subscription. The website server has been updated to Google Domains www.medmicromaps.com to increase user accessibility without restriction of login with institutional credentials.

Case-Based Guide to MedMicroMaps: Themed Office Hours using case-based learning to guide through decision tree diagnostic logic of *MedMicroMaps* were hosted as live Zoom session and recorded on Panopto and subsequently uploaded to the Panopto or Digication servers. Case materials were organized with presentation and onset, patient history, physical examinations, imaging and laboratory findings with embedded differential questions, polled with PointSolutions, and summary material from MedMicroMaps, originally authored or modified from Nath Problem-Based Learning, Sherris Medical Microbiology, AccessMedicine, Infectious Disease Society of America.

Quantitative and Qualitative User Engagement: Student participation and utilization of the various resources were assessed with extracted statistics to Excel data sheet from Panopto, Sakai, Digication and

QR Tiger. Student feedback with informed consent, including Likert 5-point scale ratings and open-ended comments, were collected on Qualtrics with a link provided via email announcement on LMS Sakai server.

3. Results

The pilot study was launched for Cohort 1 January 2020 prior to onset of COVID-19 pandemic (see Figure 1: Study Design) with the addition of the Part 1 animation on *Staphylococcus aureus* Bacterial Pathogenesis (format .mp4 hosted on Panopto) associated with required DLA (Direct Learning Activity) in Term 3 for 2nd year medical school course (Figure 2.A, Animations). All students had downloaded the PDF for the DLA (*n*=526) and 67.5% (*n*=355) of students had viewed the 2-D Panopto video by the study deadline of 1 week. Of the students who watched utilized the Panopto link, 88% (*n*=312) completed both the 2-D video (required) and the 3-D animation (optional). During Fall 2020 with virtual-only instruction for Cohort 2 post-onset of COVID-19 pandemic, the link to the Panopto 3-D animation was eliminated from the required DLA PDF and provided in virtual-only supplemental office hour (live-stream Zoom with recording hosted on Panopto), and only 2% of Term 4 medical students viewed the animation (n=18, total population = 833). Data analytics were not assessed for students enrolled in Term 4 Spring 2021 as the MedMicroMaps system was being further developed.

Instruction shifted to hybrid format in Fall 2021 with simultaneous in person and live Zoom streaming virtual delivery for Cohort 3. A link to follow-up Part 2 animation on *Streptococcus pneumoniae* Bacterial Pathogenesis (see Figure 2.B: Animations) as format .mp4 hosted on Panopto server was provided to virtual students (approximately 2/3 of population) via Zoom chat function and in person students via PDF file posted on Sakai. Within 72 hours of the link posting, 33% of Term 4 medical students viewed the animation (n=307, total population = 928). During the duration of the MedMicroMaps development, the author of the study would receive inquiries about resource posting in Sakai from students after they had completed Term 5 and were actively studying for USMLE-Step 1 Board Examination. To overcome the challenge of sorting through past semester file placement, the comprehensive e-portfolio "Microbiology Digital Media Resources" was created as a centralized location for all the supplemental material on the Digication server, including all organs system MedMicroMaps. Additional resources included Zoom and Panopto recordings of Case-Based Guides, tutorials to the MedMicroMaps systems, and infographics representing course of disease for gastrointestinal infections (See Figure 4 & 5, Supplemental Material)

Upon announcement of the website with a QR code provided to Cohort 4 students (*n*=865), scan tracking by QR Tiger showed viewing by 57.6% of the population in a single day (*n*=498), spanning 16 countries across 4 continents. Engagement on the Digication website indicated 1000+ views per module per month for subsequent Terms 4 and Terms 5 (current total views 16K at time of writing), with increased viewing the weekend prior to the module. After the final infectious disease module, 79 students (9.1% response rate) from Cohort 4 completed the Qualtrics survey. The majority of the responses indicated Extremely Satisfied (68.4%, *n*=54) or Somewhat Satisfied (12.6%, *n*=10) to "Rate your overall satisfaction with the Pathogenesis Animations" (see Figure 5). When prompted for specific utilization of the *MedMicroMap*, students ranked Exam Preparation highest (71.4%, *n*=50), followed by used with Practice Questions

(57.4%, *n*=43) (see Figure 6). Qualitative open responses indicated popularity for the animations and the decision-tree algorithms (see Table 1), represented by statement: *I really enjoyed the animation. It helped me visualize the process and understand everything better. I even showed my wife because I thought it was so interesting*. Responses included construction criticism to include antimicrobial treatments and virulence factors in the MedMicroMaps resource, which will be incorporated in future renditions of the *e*-learning resource.

4. Conclusions and Future Directions

The findings from this pilot study demonstrate the impact of instructional delivery methods on students' engagement with educational materials, particularly in the context of the COVID-19 pandemic. While the incorporation of 3-D animations alongside traditional learning material led to high levels of utilization and completion rates in a pre-pandemic setting, the transition to virtual-only instruction resulted in significantly lower engagement levels (67.5% compared to 2%). The variations of user engagement per semester were influenced by student-teacher interactions and modes of providing links to the supplemental resources with the greatest single-day engagement (57.6%, *n*=498) with the QR code linking to the Digication website provided during a synchronous, hybrid lecture. These results underscore the importance of adapting teaching strategies to meet the evolving needs and challenges faced by medical students in today's educational landscape. The educational research study is ongoing with integration of the MedMicroMaps system with accompanied e-learning tools into the 2-year infectious disease curriculum at Rocky Vista University. MedMicroMaps with the accompanying multimedia resources has been incorporated in the curriculum design of Microbiology, Immunology and Infectious Disease course. An introductory map slides for pre-recorded PPT session was created with instructor reinforcement of spatial positioning (see Figure 8: Viral Map) organized with biological classification and was provided for all viruses, half of bacteria and none of eukaryotic agents. A Qualtrics feedback survey with informed consent will be administered following the completion of the course with 6-month and 12-month assessment for biological classification recall accuracy. Lastly, the MedMicroMaps system with the comprehensive decision-tree logic was originally designed for immersive technologies including Virtual, Augmented, and Reality developing in the Metaverse (collectively referred as XR Extended Reality). Visually engaging study materials are readily adaptable to XR platform, leveraging the computational advantages conferred by generative artificial intelligence, with the ability for the learner to scale down to the invisible microscopic world with a 1 nanometer viral particle fitting in the palm of the hand (Figure 9, Supplemental Material). The future of MedMicroMaps in cross-platform interfaces envisions storylines covering all infectious diseases, with adaptable design for diverse audiences within allied health fields, including those in allopathic and osteopathic medicine, nursing, pharmacy, graduate biomedical and veterinary sciences, with skill levels ranging from advanced placement high school biology to practicing physicians.

Figure 1 Pilot Study Design

Medical students in 2nd year basic sciences courses at a USA-accredited Caribbean medical school were provided supplemental digital media resources corresponding to microbiology lecture modules with delivery formats changing from in-person, Zoom-based virtual, and hybrid formats in response to pandemic restrictions. Resources included animations, novel mind map MedMicroMaps, case-based office hours, and infographic illustrations for gastrointestinal infections, provided on course LMS, Panopto or Digication servers.

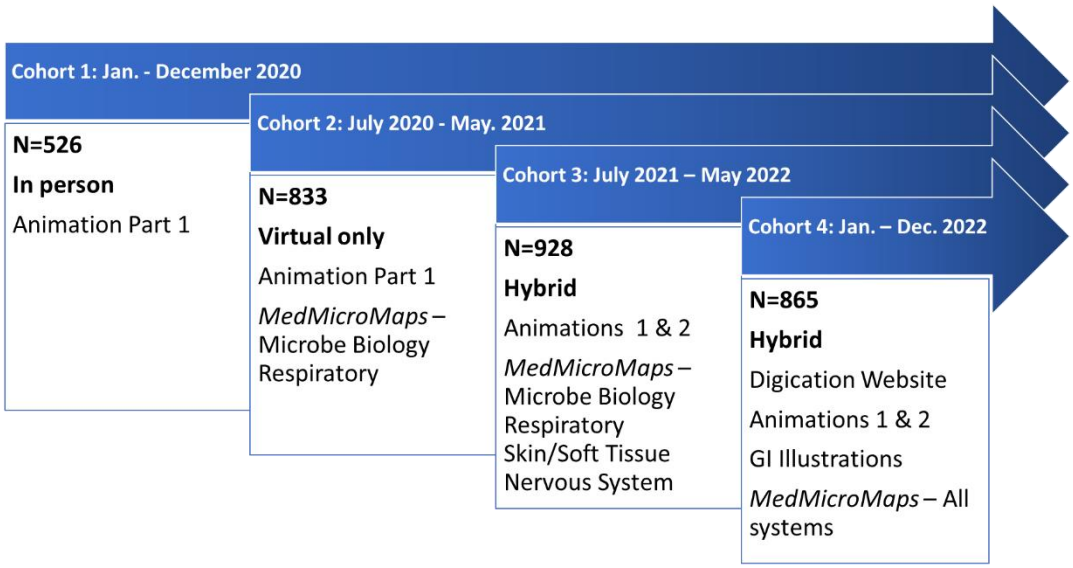


Figure 2 Pathogenesis Animations

In collaboration with SGU Center for BioMedical Visualization, 3-D pathogenesis animations (A. Part 1: *Staphylococcus aureus*, B. Part 2: *Streptococcus pneumoniae*) were created to illustrate complex host-pathogen interactions. Animations were provided as supplemental material hosted on Panopto or Digication website server. User engagement and student feedback were assessed with the respective server statistics and a Qualtrics survey.

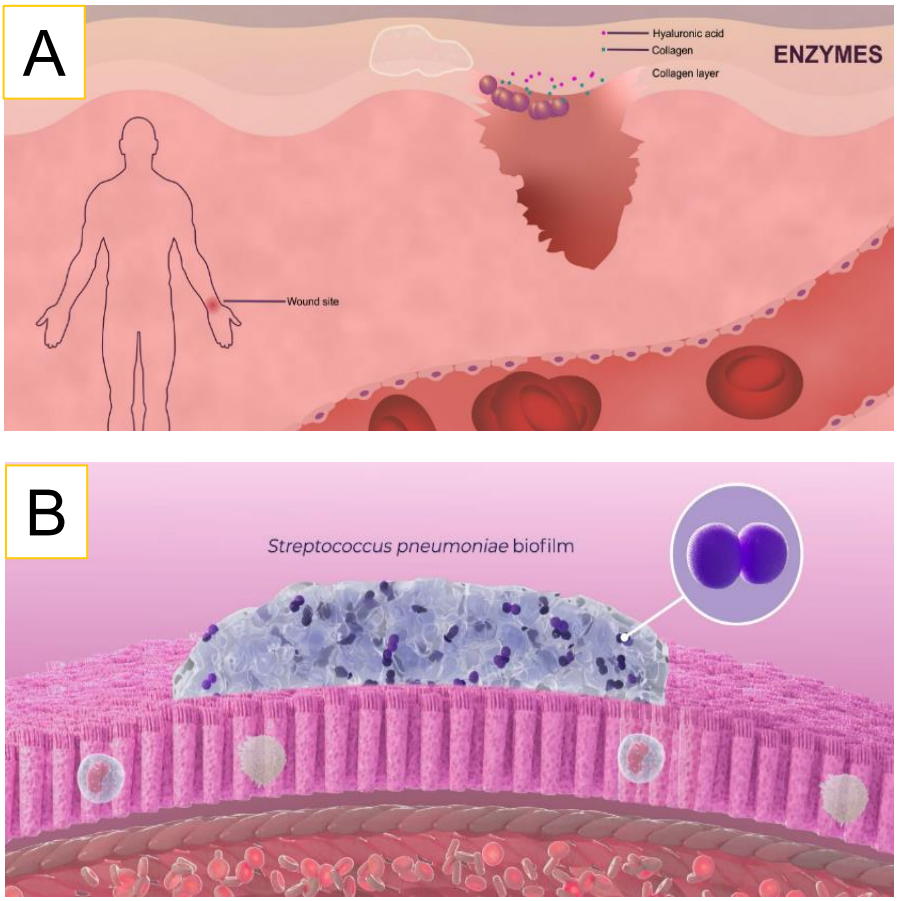


Figure 3: Infographics Illustrating Course of Disease for Gastrointestinal Infections.
Medical illustrations were created to demonstrate the course of disease for gastrointestinal infections, specifically showing the host and bacterial interactions of Entero Pathogenic *E coli (*file with animations available in supplemental material). Illustrations provided diversity of patient representation to correspond to epidemiological incidence.

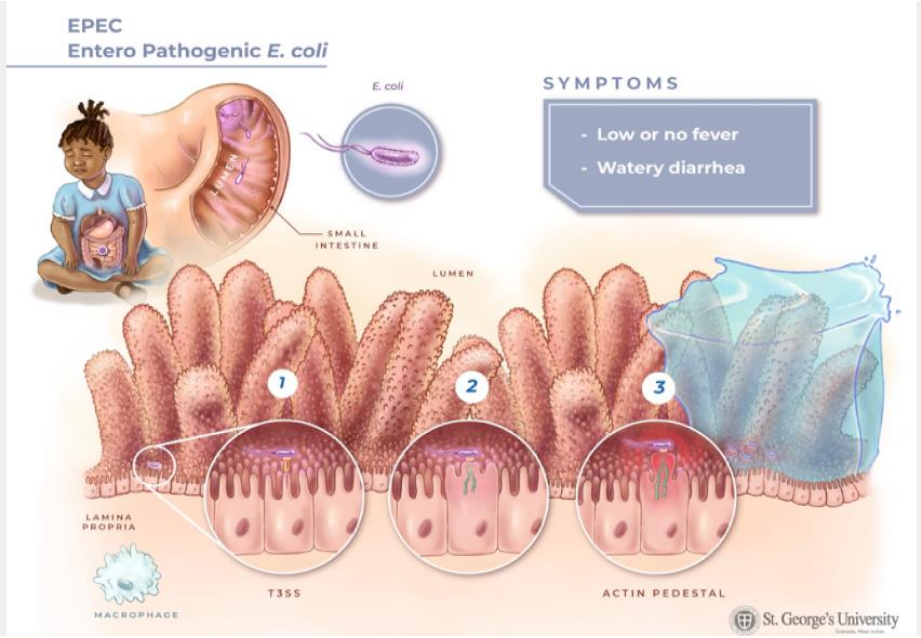


Figure 4 Representation of Respiratory *MedMicroMaps* Diagnostic Algorithm

An interactive guide of infectious diseases on PowerPoint platform was developed for preclinical medical students, using the principles of mind maps and Method of Loci to create a consistent color-coding and spatial patterns arranged on a compass with cardinal directions to emphasize decision-tree logic. Embedded hyperlinks routes the user through differential diagnoses, following the content order of board-style vignettes.

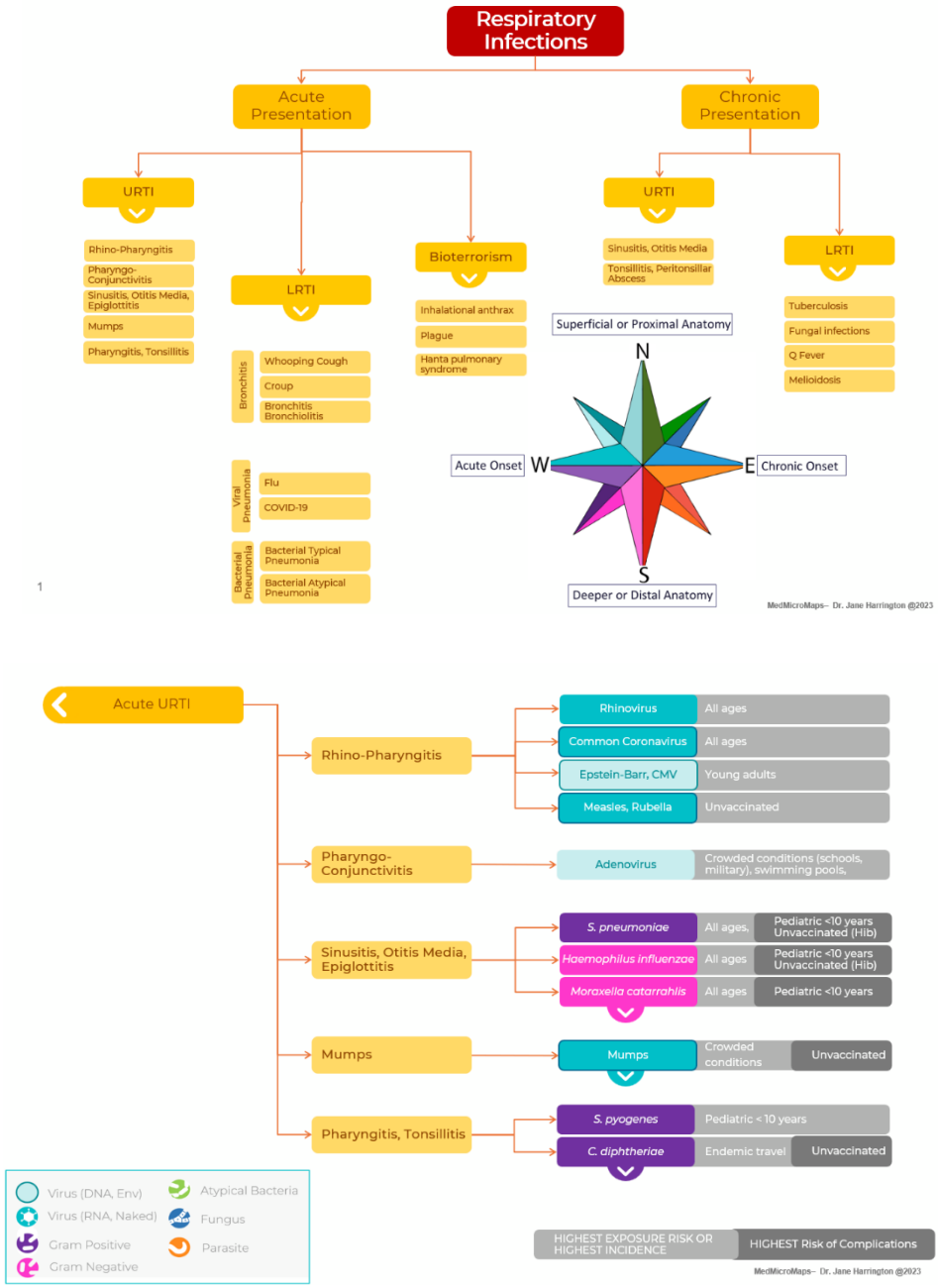


Figure 5: Student Engagement with Multimedia Resources

Bar graph illustrating the levels of user engagement for Cohort 1 (pre-pandemic) using Panopto, measured by the percentage of PDF downloads and viewership categories. The red bar indicates the proportion of students who downloaded PDFs, while the green, blue, and orange bars represent the students who viewed the PDFs at rates of >65%, 65%-15%, and <15%, respectively. The Y-axis indicates the percentage of students participating in each category.

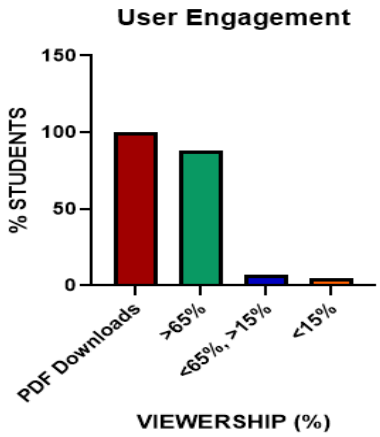
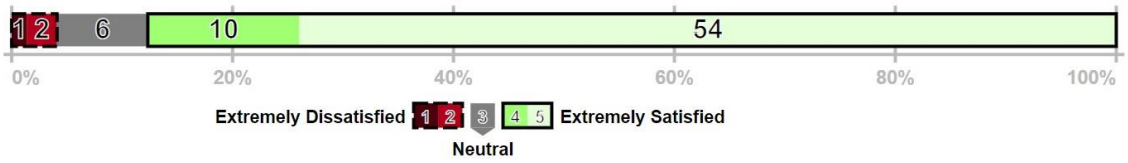


Figure 6: Qualitative Student Feedback.

A 5-point Likert scale representing Cohort 5 student responses were asked how satisfied they were using supplemental digital media resources.

A. Rate your overall level of satisfaction with Pathogenesis Animations.



B. To what extent do you agree that the Respiratory Infections MedMicroMaps enhanced your learning experience with the material covered in this module?

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Figure 7: Distribution of User Preferences for the MedMicroMaps: Stacked bar graph representing the usage of MedMicroMaps by students within two different systems: the Central Nervous System (CNS) and the Respiratory Infections modules. The segments within each bar indicate the number of students engaging with the resource in different ways, categorized by activities such as preparing for module exams (red), doing practice questions (dark orange), following module lectures (light orange), referencing during themed office hours (yellow), and not using MedMicroMaps (beige). The horizontal bars indicate the total number of students for each category and system.

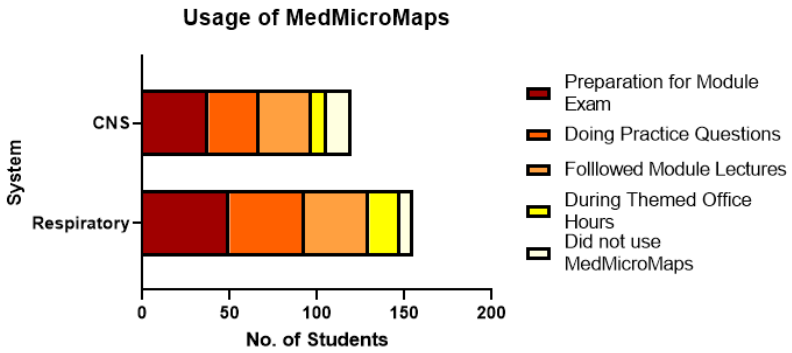

Figure 8: Green Screen Video Recording of MedMicroMaps. A representative GIF of instructor presenting a section of MedMicroMaps, specifically the Skin and Soft Tissue Infections portion including Viruses. Spatial repetition is incorporated into required student directed learning materials delivered as pre-recorded videos on Panopto server.

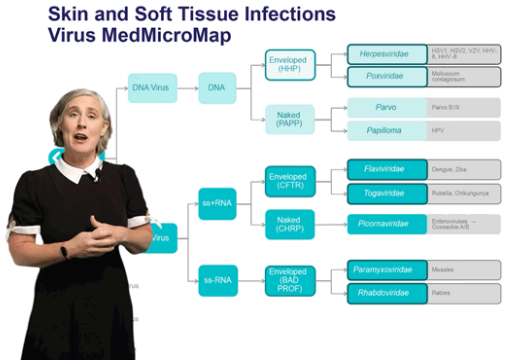

Figure 9: MedMicroMaps Trailer Created with Generative Artificial Intelligence

The computational processing powers of large language models, including generative AI program Pixverse are a new avenue to exploring the microscopic world of MedMicroMaps by creating images and videos of infectious agents that fit in the palm of a human hand.

Table 1 Qualitative Feedback from Cohort 4 Medical Students. Table 1 represents feedback received on MedMicroMaps, where positive feedback is depicted on the left, and negative feedback is shown on the right.

Please provide any feedback on Microbiology digital resources (open response).

Positive Feedback	Negative Feedback
The MedMicroMaps were a great resource to help organize and consolidate the information needed on the microbes. They were an important resource for me that I referenced during class, doing practice questions, and studying for the exams. The format for the office hours was helpful in practicing cases and understanding what was important in each topic.	Not a fan of flow charts to begin with but the flow charts can be improved in the design aspect, visually.
Digital visual resources make studying much interesting and easy to retain. These charts also help to connect all the dots as you progress in learning new infections	None were useful. All was thought for detail learning instead of pattern learning ways.
The digital resources including the Med Micro Map were my primary source of information and study reference for all of the microbiology content from Terms 4 to 5 and I continue to use the PDF to review the material.	Match treatments earlier, helps compartmentalization. (Regardless if tested on the upcoming exam)
I really enjoyed the animation. It helped me visualize the process and understand everything better. I even showed my wife because I thought it was so interesting.	it was not useful in ruling out choices, just showing what groups orgs fall in. i tried to use it answering questions, but not helpful and was cumbersome.
LOVED the med micro maps, but some of the links don't work to go forward to a microorganism or back to the overview slide.	I would have loved the micro map to have a roadmap slide that also included the virulence factors and all the other necessary information all on 1 page
Loved the roadmaps and animations created!! super helpful and helps link the dots between microbe & diseases	CNS micro map doesn’t appear to be on Course-LMS yet

5. Statement of Ethics

Ethical Review

The investigations of this study were compliant with ethical practices established by Nuremburg Code. The educational research project was submitted to the Internal Review Board at St. George's University and was determined to fit the criteria for exemption for full review prior to initiation of study investigations. An electronic informed consent was provided to participants and confirmation of consent was obtained for feedback survey responses.

Statement of Competing Interests

The author of the article had no conflicting established partnerships of financial or non-financial support during the pilot study and held an academic position at St. George's University. No funding agencies contributed to the pilot study. The corresponding author of the article currently holds an academic role at Rocky Vista University and has recently established a start-up company MedMicroMaps, LLC. to apply for grant funding with the National Science Foundation, Small Business Innovation Research program. MedMicroMaps, LLC. has no established financial relationships with external funding partners.

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