Using Virtual Simulations in Online Laboratory Instruction and Active Learning Exercises as a Response to Instructional Challenges during COVID-19

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The onset of the COVID-19 pandemic in Spring 2020 thrust instructors into a world of frenzy, presenting unique challenges to delivering course content. Especially challenging was how to substitute wet lab experiments that often comprise science labs. Recognizing that this problem was not short term, I started to look into virtual substitutions to be implemented in the 2020-2021 academic year. Virtual simulations can replace labs, be incorporated as prelab assignments, or used as active learning or experiential learning exercises in a traditional classroom setting while providing low cost, safe and acceptable solutions to the current problem. Virtual simulations were examined in different platforms. These included Labster, McGraw Hill Connect Virtual labs, HHMI Biointeractive, Learn Genetics, Virtual Interactive Bacteriology Laboratory, and Biology Corner. The goal was to provide faculty around the world a reference list of virtual simulations that are aligned to specific AAAS and ASM student learning outcomes. These simulations are discussed here in terms of content, features, and advantages of use, as well as a list of lab exercises aligned to biology courses (microbiology, genetics, and cell biology).

INTRODUCTION

The current COVID-19 pandemic has forced many instructors to incorporate more online course delivery mechanisms while still retaining student learning outcomes. The rapid transition exposed the challenge of teaching science courses with a laboratory component, posing questions that included: How do you convert a hands-on lab to an online lab? Can we use these simulations for experiential and or active learning? Studies show that use of gamified laboratory simulations and active learning increase student interest, motivation, learning effectiveness, and self-efficacy (2–4). Furthermore, active learning decreases learning gaps, thus increasing student achievement (5). Advantages to virtual laboratory simulations include cost-effectiveness, eliminates biosafety concerns, and increases engagement of digital aged students (2). Many of these simulations are associated with real world problems, such as stem cell therapy to treat blindness, visualizing cancer cells to distinguish unique characteristics, and analyzing DNA to solve a crime.

Here, I review simulations in general biology, microbiology, genetics, and cell biology from Labster, HHMI Biointeractive, and various other online sources. My goal was to provide instructors who are looking to transition into online delivery a resource that aligns laboratory topics traditionally incorporated into in-person lab sessions with virtual simulations (Table 1, Appendix 1).

PROCEDURE

Virtual simulations from Labster, McGraw Hill Connect, Virtual Interactive Bacteriology Laboratory, HHMI biointeractive, Learn Genetics, and Biology Corner were reviewed for content, delivery, and assessment (Appendix 2 and Appendix 3). Each simulation can be used as an active learning or experiential learning activity, a stand-alone lab in an online course, or as a prelab assignment for a physical lab. For example, an instructor can implement a weekly virtual lab with prelab introduction video about the goal of the lab, brief background on the topic, and highlight some theoretical concepts discussed in lecture. Most of the simulations reviewed have a built-in quiz, assignment, and student handout. A post-lab quiz administered online or in person can also be used to assess learning outcomes.

As mentioned previously, various simulations from different sources were reviewed. Table 1 shows virtual lab options in microbiology along with ASM fundamental statements and Vision and Change core concepts and competencies covered in traditional microbiology labs (6, 7). Additionally, the microbiology labs in Table 1 also satisfy the Microbiology Laboratory Skills as outlined by ASM curriculum guidelines (Table 1). Many of these labs can be cross-listed across curricula. Labs used in other biology courses are listed in Appendix I. Appendix 3 lists the benefits and drawbacks of each simulation provider. Along with basic
TABLE I
Microbiology virtual simulations aligned with ASM core concepts and Vision and Change competencies

| Virtual Simulations with Core Lab Techniques | ASM Competencies and Skills (#) | Vision and Change Core Concepts (Italicized) and Competencies (AAAS 2011)* |
|--------------------------------------------|--------------------------------|--------------------------------------------------------------------------------|
| Microscopy lab\textsuperscript{a,d} Bacterial Cell Structures\textsuperscript{a,c} | Properly prepare and view specimens for examination using microscopy (bright field and, if possible, phase contrast) (32). | - Structure and function  
- Ability to use modeling and simulation. |
| Gram Staining\textsuperscript{a,c} | Use appropriate methods to identify microorganisms (media-based, molecular and serological) (34) | - Structure and function  
- Evolution  
- Tap into the interdisciplinary nature of science  
- Communicate with other disciplines in science  
- Apply the scientific process. |
| Bacterial isolation\textsuperscript{a}  
- Sterile technique  
- Colony screening  
- Plate streaking | Use pure culture and selective techniques to enrich for and isolate microorganisms (33). | - Structure and function  
- Evolution  
- Apply the scientific process. |
| Bacterial quantification:  
Count bacteria with serial dilution\textsuperscript{a}  
- Serial dilution  
- CFU calculation  
- Aseptic Technique | Estimate the no. of microorganisms in a sample (using, for example, direct count, viable plate count, and spectrophotometric methods) (35). | - Structure and function  
- Apply the scientific process.  
- Use quantitative reasoning  
- Ability to use quantitative reasoning. |
| Antibiotic susceptibility\textsuperscript{a,c}  
- Kirby-Bauer disk Diffusion Assay | Use appropriate methods to identify microorganisms (media-based, molecular and serological) (34).  
Use appropriate microbiological and molecular lab equipment and methods (36). | - Evolution  
- Structure and Function  
- Information flow, exchange, and storage  
- Apply the scientific process.  
- Ability to understand the relationship between science and society.  
- Tap into the interdisciplinary nature of science  
- Communicate with other disciplines in science. |
| Control of microbial growth:  
Explore decontamination and selective toxicity\textsuperscript{a}  
- Diffusion Disc Assays  
- Decontamination methods  
- Sterilization techniques | Use appropriate methods to identify microorganisms (media-based, molecular and serological) (34).  
Use appropriate microbiological and molecular lab equipment and methods (36).  
Practice safe microbiology, using appropriate protective and emergency procedure (37) | - Evolution  
- Structure and Function  
- Information flow, exchange, and storage  
- Apply the scientific method  
- Ability to understand the relationship between science and society. |
| Bacterial identification:  
HHMI Bacterial identification based on DNA sequence\textsuperscript{a}  
Identification of Unknown Bacteria: Help save baby Kuppelfangs from an epidemic!\textsuperscript{a} | Use pure culture and selective techniques to enrich for and isolate microorganisms (33).  
Use appropriate methods to identify microorganisms (media-based, molecular and serological) (34).  
Document and report on exptl protocols, results and conclusions (38). | - Information flow, exchange, and storage  
- Evolution  
- Structure and function  
- Apply the scientific method  
- Ability to understand the relationship between science and society.  
- Tap into the interdisciplinary nature of science  
- Communicate with other disciplines in science. |

\textsuperscript{a}Labster.  
\textsuperscript{b}https://www.biointeractive.org/classroom-resources/bacterial-identification-virtual-lab.  
\textsuperscript{c}Virtual Interactive Bacteriology Laboratory (http://learn.chm.msu.edu/vibl/content/antimicrobial.html).  
\textsuperscript{d}Biology Corner https://www.biologycorner.com/worksheets/microscope-virtual.html.  
\textsuperscript{e}Vision and Change (AAAS 2011).
criteria such as scientific procedure, pre- and postlab assessment, lab handouts, and technology needs, a scale of 1 to 5 that describes the “immersive” content of each simulation provider was developed to describe the real-life resemblance to a physical lab (Appendix 3). Each simulation is assigned a score based on engagement, real world application, and degree of complexity. A score of 5 is considered completely engaging and immersive and defined as follows: “uses a “bot” to navigate the lab; requires use of lab procedures and equipment as done in physical labs (slide preparation, solution prep, incubator, microscope, pipette, etc.). Criteria for scores 1 to 4 are outlined in Appendix 3.

In both Labster and McGraw Hill Connect simulations, the instructor can choose a laboratory from a list of science disciplines (Appendix 2). Labster provides simulations for topics in multiple biology disciplines, including general biology, microbiology, genetics, and cell and molecular biology. However, the biology-related simulation topics are limited in McGraw Hill Connect Virtual Labs (Appendices 2 and 3). In both, each lab contains 3D graphics that mimic a real laboratory environment so that the student understands the general lab setup, use of equipment, and follows typical experimental procedures. These simulations also address specific student learning outcomes with hypothesis-driven experiments, analysis of results, and generation of conclusions. Most of the labs have an experiential component, such as identifying pathogenic bacteria, using stem cell therapy for treatment, and developing a detection assay for hemophilia. The use of realistic and practical scenarios supports the use of these simulations in an experiential learning environment. Both of these virtual simulation packages offer built-in assessment, where Labster has a limited number of multiple-choice questions and McGraw Hill Connect provides pre- and postassessment options from a test bank. Labster was used in Fall 2020 for an upper-level genetics course at Culver-Stockton College. Lab topics included cell division, cytogenetics, molecular cloning, PCR, and next-generation sequencing. Simulations were chosen based on topics previously covered during in-person labs. Students appreciated the immersive nature, 3D reality, and application. They felt that it was an adequate substitute for in-person experiments. Most simulations were completed in 1 h. An example of a post-lab assessment for one of these labs is provided in Appendix 4.

McGraw Hill Connect Virtual labs was used in a non-major general biology lab in Fall 2020. Lab exercises on scientific method, scientific measurement, diffusion and osmosis, enzyme function, and cellular macromolecules were used. These labs were less immersive, and not all were data driven. Post-assessment was administered in exams and most students were able to answer questions based on these simulations. Students were able to complete the simulations in the allotted time with an average time of 30 min for each assigned exercise.

HHMI Biointeractive labs, Learn Genetics, and Biology Corner online resources available via a URL link (see Table 1; Appendix 1) were also reviewed. While these sources are limited in terms of immersive reality, experiential component, and assessment, they may serve as viable substitutes for in-person labs, but they may be better as pre-lab assignments or active learning exercises in lecture. All of these labs are accessible free of cost. These simulations are more like animations can be incorporated in multiple biology courses, highlight the various experimental techniques, resources, and applications, and require some aspect of “hands-on” activities, which involve a point-and-click action. These labs do not include imbedded assessment but some do have a student lab handout. An HHMI Biointeractive lab on “Bacterial Identification” can substitute for the unknown bacteria project incorporated into every undergraduate microbiology course involving identifying bacteria. This simulation uses 16S ribosome sequence, DNA isolation, and sequencing (Appendices 1 and 2). HHMI Biointeractive also has labs on evolution, genetics, and immunology (ELISA).

Learn Genetics provides options for virtual labs that are limited to molecular biology, such DNA extraction and PCR. These labs are somewhat realistic and have minimal application. Biology Corner has extensive options of animations and some experiential exercises which can be incorporated into a lab (many labs are for physical experiments). One such activity is on karyotyping. The author of the exercise has generated a click-and-sort activity to diagnose three genetic disorders based on karyotypes. This activity was used in Fall 2020 Genetics course after a lecture on meiosis and substituted for a similar activity provided in a lab manual (12). The activity was less tedious than a paper exercise that involved clicking and dragging action to form homologous chromosomes pairs. Students worked independently on one of the four karyotypes assigned and then compared results after diagnosis. Once a diagnosis was verified, students were asked to investigate prognosis and treatment for each disorder, citing evidence from primary literature. Topics of these labs are listed in Appendix 1, and Appendix 3 lists features of each simulation.

CONCLUSION

The information presented here aligns traditional physical labs with useful virtual simulations. The demand for virtual simulations that mimic traditional physical labs will only increase with time (1). The use of virtual labs even as a supplement can only enhance science learning and performance (3, 7, 8). Both physical and virtual labs can achieve similar learning outcomes, such as interaction with theoretical concepts, hypothesis development and testing, and data collection and analysis, as well as developing team work, inquiry skills, and increasing interest in science (8, 9). Several studies have shown that active learning using simulations improves conceptual learning, retention, motivation, and study intensity as well as narrowing the achievement gap in
underrepresented STEM students (2, 3, 5, 7, 12). Furthermore, virtual and online alternative inquiry-based labs have been viewed favorably by students (10). Additionally, students using virtual labs are less likely to be distracted by measurement errors (10) or multiday procedures that can get complicated and often lead to “failure” while instantly producing data for reflection, allowing instructors to identify student understanding (8). While it is important for students to experience failure in lab and develop problem-solving skills, it can be acknowledged that these negative experiences often mask the desired student outcomes.

SUPPLEMENTAL MATERIALS

Appendix 1: Comparison of in-person and bench labs with virtual lab options
Appendix 2: List of virtual laboratory simulation packages
Appendix 3: Noncomprehensive list of features (benefits) of assessed virtual simulations
Appendix 4: Example of post-assessment quiz for genetics lab simulation on cytogenetics

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