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Student Perceptions of the Online Introductory Biology Laboratory Curriculum Using a Framework of Vision and Change and its Core Competencies

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Abstract

In response to the COVID-19 pandemic, an Introductory Biology course at a private university was reformatted to an online format. To examine student perceptions of the effectiveness of the laboratory portion of the course, a researcher designed questions based on the *Vision and Change* core competencies and presented them to a representative sample of students in virtual interviews. The themes which emerged from the student responses were that students had positive views of their comfort level with the scientific method, the virtual laboratory synchronous format, worksheet activities, breakout rooms, and lessons with social relevance to college-aged students.

Key Words: Vision and Change, virtual, online, biology laboratory, undergraduate

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Chapter 1
Introduction

With the Internet available on computers, tablets, phones, and even glasses, it is not productive for biology students to spend their time memorizing vocabulary words to be regurgitated onto multiple-choice tests. A typical science education course is historically broken into two formats. In the first portion, the students experience a lecture setting, formatted as a typical presentation by a speaker focusing on memorization, or formatted as a flipped classroom, where the students participate in an activity to expand on readings they have done during their own time. The other portion of the course is found in a laboratory setting, where students engage in hands-on, inquiry-based lessons. As the Internet offered instant recall for details students would have memorized before the Internet, what was demanded of students came into question.

In 2009 an expansive survey of biologists and educators, under the direction of the esteemed American Association for the Advancement of Science and the National Science Foundation, put together a report, entitled *Vision and Change in Undergraduate Education* (American Association for the Advancement of Science, 2011), focusing on skills and limited topics that should be the focus of Twenty-First Century science education. In *Vision and Change*, the authors assert that students need to be flexible, dynamic, critical thinkers. They must be able to think like scientists, questioning and examining, collaborating, and analyzing. They need to grasp the basic tenets of biology, understanding evolution, structure and function, information flow, pathways and transformation of energy, and systems, and they need a proper set of tools with which to work, They need the ability to apply the process of science, quantitative reasoning, modeling and simulation, a grasp of the interdisciplinary nature of science,

willingness to communicate and collaborate with other disciplines, and the ability to understand relationships between science and society (AAAS, 2011). It is the instructor's job to nurture these skills in their students. Learning biological content through experimental design and data analysis, while fostering openness to collaboration and innovation, will lead them to an effective comprehension of the biological world around them.

Colleges and universities--from gargantuan state universities to smaller four-year private colleges to community colleges to online programs--are trying to adopt the concepts established by the *Vision and Change* meetings for the modern needs of biology students (Gonzalez, 2016). Different approaches are needed for the differing circumstances of each type of educational institution. Professors can look at the outcomes they wish their students to achieve and model their lessons to convey the new skills and terms. In the case of online education, the lectures could be converted with some ease, using videotaping, video conferencing, and online platforms such as Blackboard, GoogleMeets, Microsoft Teams, or Zoom. Can the 4 C's of education—Creativity, Collaboration, Critical Thinking and, and Communication (Trilling & Fadel, 2009)— be as successful using online laboratories?

An online laboratory has to incorporate the four C's creatively and seamlessly. Students may watch as an instructor conducts the experiment, watch videos detailing a concept, interact with websites dedicated to an educational topic, or synchronously meet up on video meeting platforms for discussion, evaluation, group work, or question and answer sessions. To feel the synergistic effects of collaboration, there needs to be something tying them together. Student feeling of attachment and involvement can influence their experience, and, thus, their educational outcomes.

In my capstone research, I examine student perceptions of the online laboratories for Introductory Biology in the Department of Biology and Earth Science. This 4-year liberal arts college department has a strong enrollment with programs in Biology, Sustainability, Environmental Science, and Zoo and Conservation Science. The students use the degree programs for a pre-medical pathway, to prepare for graduate school, or for careers in industry or academia. To give them the scientific background needed, educators have a responsibility to make them competent, critical thinkers, capable of analyzing the mechanisms by which change occurs. Educators have a responsibility to teach them to think like scientists.

Taking the collective advice of the American Association for the Advancement of Science and the National Science Foundation, two of our most esteemed collectives of scientific thinkers, we can design modern science curricula that make our students dynamic, critical thinkers, capable of adapting to the quick changes that occur in modern technology. I use interview questions based on the core competencies described under *Vision and Change*. With *Vision and Change* as my guideline, I engaged students in conversation to assess the effectiveness of the online laboratories. Are students learning to apply the process of science, engage in quantitative reasoning, modeling, and simulation, grasp the interdisciplinary nature of science, demonstrate a willingness to communicate and collaborate with other disciplines, and understand relationships between science and society?

The university hosting this research has a history of being at the forefront of change, being one of the first universities to welcome women and persons of color into the university environment, taking an active stand on LGBTQ rights, and continuously embracing an idea of improvement through social evolution. With this history of adaption, it is fitting to have this university openly engage in curriculum analysis in response to a critical challenge.

Consequently, I propose my capstone is an inquiry study using interviews to determine student perceptions of the online Introductory Biology laboratories.

Chapter 2

Literature Review

In the year 2020, educators were forced to innovate with haste beyond their usual innovative speed. When the COVID-19 outbreak reformatted universities across the United States, faculty in the sciences were challenged to convert course plans to online models with urgency and a notable focus on the safety of students and faculty. With dual inclinations, pulling toward the ideal model of hands-on science education (American Chemical Society, 2017; National Research Council, 2012), which favors problem-based learning and inquiry methods of teaching (Furtak et al., 2012; Schroeder et al., 2007; Weir et al., 2019), and the desire to conquer this task of developing effective, online content, biology instructors adapted. This study focuses on the success of this transition to online laboratory experiences from the student point of view. Assessing the students' views of the online laboratories, while the memories of the semester are still recent, is the focus of this study.

This review begins by examining the currently recommended parameters of science education, including the competencies we have collectively established as desirable in successful biology graduates. We will, then, look at online formatting, breaking this down from general online courses to online courses within STEM fields, to STEM laboratories, to online biology laboratories, and, finally, to previous work in evaluating the success of online courses within these categories.

Science Education

Recent consensus supports hands-on, inquiry-based teaching strategies for effective science education. The laboratory component of science courses has been the cornerstone of this strategy. In an American Chemical Society policy statement (2017, p. 1), the society summarizes this sentiment, "Research has shown that students who engage in well-designed laboratory experiences develop problem-solving and critical-thinking skills, as well as gain exposure to reactions, materials, and equipment in a lab setting." While this statement addresses chemistry laboratories, the statement can be applied to the biological laboratory.

Biological Education

As the 21st century began, the state of biology was changing so quickly that biological education needed to keep pace. In a field where students had previously viewed the courses as memorization of vocabulary and concepts, scientists and educators now felt that the students were not being well-served. The field had become dynamic, quickly growing, and with many blending outlines where it met and interacted with other sciences and fields. Faculty found that trying to look at too many topics led to rushed semesters in which little was examined in detail (Gregory et al., 2011). In 2007, faculty, scientific staff, and higher education students participated in surveys, conversations, and workshops initiated by the American Association for the Advancement of Science and the National Science Foundation on a fact-finding mission. In July 2009, the American Association for the Advancement of Science and its collaborating associations met to discuss curriculum needs of undergraduate education (Woodin et al., 2012) and to incorporate and collate those ideas into a report intended to provide structure biology education practice.

Vision and Change in Biology Education

The results of the meeting were printed in a report published in 2011(AAAS, 2011) available online. The report presented the key scientific literacy needs of 21st-century biologists: (1) Evolution, (2) Structure and Function, (3) Information Flow, (4) Pathways and Transformation of Energy, and (5) Systems. The report also listed the core competencies and disciplinary practices needed for implementation. These are (1) the ability to apply the process of science, (2) the ability to use quantitative reasoning, (3) the ability to use modeling and simulation, (4) the ability to tap into the interdisciplinary nature of science, (5) the ability to communicate and collaborate with other disciplines, and (6) the ability to understand relationships between science and society. These key topics and core competencies were needed in the coursework of the students, and, to focus on acquiring needed skills of scientists, educators were going to determine how much ~~of the~~ memorization of vocabulary their new, dynamic courses were going to entail. Courses needed to be active, student-centered, and outcome-driven, teaching the students to think critically and actively learn. Memorization would become supplemental, not integral (French, 2012).

Change became imminent as researchers noticed the new landscape of the biological sciences and perceived that education needed to keep pace (French, 2012; Gregory et al., 2011). Vision and Change offered specific recommendations to overhaul the undergraduate curriculum. Updates were made to the Advanced Placement Biology curriculum (College Board, 2020) and the K-12 curriculum (National Research Council, 2012). The *Vision and Change* report is strongly supported by the National Association of Biology Teachers (French, 2012; Little, 2013; McLaughlin & Metz, 2016), the association responsible for the production of *The American Biology Teacher* journal as well as maintenance of an invaluable database of biology teaching

resources. The aforementioned articles guide readers to resources giving general statements of support, and historical reference to the thinking behind the curriculum recommendations. With the variability of educational environments and instructor interpretation, the implementation of the structural topics has been inconsistent.

The BioCore Guide, described by Brownell (2014) used the key concepts and core competencies to develop a flowchart of summary statements. Colleges and universities can use that flowchart to develop their core curricula with Vision & Change's recommendations integrated into the framework. Another university designed group engagement projects, which they utilize in one out of every three class times to encourage student group work, forming hypotheses, discussing concepts, and making sense of the scientific phenomena or systems that are the focus of the day's task (Jardine et al., 2017). Based on Vision and Change, Lysne and Miller (2015) implemented six learning modules that give students an in-depth view of their topics. Students begin with a guided question-and-answer, do an activity, take in a lecture on the topic, reflect, then receive an assessment. The concept behind this is a cartwheel process, where students engage, explore, reinforce, assess, and repeat, giving them a systemic experience with each topic.

Universities, of variable sizes and format, have responded to the recommendations, taking approaches that reflected their student body size, university resources, and the format of the university as a whole. One of the largest universities in the country, Arizona State University, adopted the recommendations by focusing on flipped courses, replacing one lecture per week with an "Active Learning Classroom", and designing laboratory courses around open-ended inquiry lessons. Using multimedia resources, Innovative Teaching Assistants, and writing-intensive first semester courses, the university has integrated *Vision and Change* principles into

the Introductory Biology sequence as well as upper-level courses (Vanmali, 2014). Vanmale defined "Innovative Teaching Associates" as incoming graduate students required to complete a Scientific Teaching course introducing them to learning theories and active-learning strategies for collegiate science teaching.

Due to the consistent agreement upon the *Vision and Change* recommendations, it is an appropriate backbone for determining course effectiveness. Limiting required topics to evolution, systems, and the other key concepts frees the instructor to focus on their desired specialties and apply them with depth and breadth. The scientific competencies described (Appendix A by the report incorporate organically into a well-designed semester of biological education

Online Classrooms

When standard classroom formats were overhauled in the spring of 2020 due to surging numbers of a highly contagious respiratory disease, professors re-vamped curricula quickly and with good intentions. With effort, it seemed that lectures could be converted to an online format with effort and probable success. How well would laboratories be converted? How effective would the new formats be at bringing students to view themselves as successful scientists? To answer these questions, I focused on the core competencies mentioned in *Vision & Change* 1) the ability to apply the process of science; 2) the ability to use quantitative reasoning; 3) the ability to use modeling and simulation; 4) the ability to tap into the interdisciplinary nature of science; 5) the ability to communicate and collaborate with other disciplines; 6) the ability to understand relationships between science and society (AAAS, 2011). I wanted to know whether students acquired these skills in an online laboratory curriculum?

Online courses are not new, with universities integrating computer use into courses back to the 1960s and internet-based education burgeoning in the mid-1990s. Courses have been offered for distance learning, homeschooling, convenience, and good-willed dissemination of free knowledge (Tom, 2017). Face-to-face learning remained the standard format; however, online courses were accepted and improved by those focusing on the niche (Means et al., 2010; Miller et al., 2018; Ofgang, 2020). A report from the Partnership of the Future of State Universities and Meane's Department of Education meta-report indicated that online learning had value and could have equal, if not better, learning outcomes, depending on the interaction of the professor and the set-up of the course (Academic Partnerships for the Future of State Universities, n.d.; Means et al., 2010). Likewise, Nguyen's 2015 meta-study found that online education could be effective and have the benefit of making world-class education accessible without locational barriers (Nguyen, 2015).

Methodologies were developed for comparing the efficacy of online courses to their traditional counterparts. A meta-analysis by Castro, et al (2019) described an evaluation framework of Analysis, Design, Development, Implementation, and Evaluation (ADDIE) for comparing, identifying important components of the delivery, and evaluating institutional adoption of the online format to score the studies within their meta-analysis. A study conducted by the Partnership of the Future of State Universities (2011) found that recent research had identified a change in perception, with many courses reporting success in learning outcomes which were equivalent between traditional face-to-face formats and online formats (Ofgang, 2020). These studies supported the overall potential of online education in a general education curriculum. Could online education be effective in the Science, Technology, Engineering, and Mathematics area?

Online Science, Technology, Engineering, and Math

There is allure in the widespread availability of the world's greatest instructors. TEDTalks—available for free online, MasterClass lectures—a subscription service, open-source courses (edX.org, 2019), reading lecture notes from Richard Feynman, (Feynman et al., 2013)—there is a calling for these sources of knowledge to be recorded, stored, and shared. In Cirulli's (2016) study looking at the use of Massive Open Online Courses in 2016, freely-available online complete courses, the ability to personalize the content was key for the appeal of online professional development in the technology field. As a counterpoint, however, urban students using online content to recover missing credit in Algebra found it more difficult, or found more obstacles to their achievement, than students who re-take the course in traditional face-to-face format (Heppen et al., 2017), and Biology undergraduate students preferred live lectures to recorded lectures as learning tools (Simcock et al., 2017).

In STEM laboratories, online courses receive a grade of "no difference" at best. Multiple studies comparing online and traditional science laboratory courses (E. K. Faulconer & Gruss, 2018; Rowe et al., 2018) or Physics laboratory courses (E. Faulconer et al., 2018; Miller et al., 2018) found no clear advantage, nor deficiency, between online or face-to-face laboratory courses.

Online Biology

We will now focus on online biology laboratory research. Gonzalez, in a 2016 study at a two-year community college in Florida, discussed the complexities, successes, and shortcomings of implementing Vision & Change in an online biology course (Gonzalez, 2016). She mentioned

curriculum development as a complexity, in that their online courses follow course-design outlines from a rubric known as the Quality Matters (2020) rubric for higher education (Maryland Online Consortium, 2020). At the same time, coming from a background of face-to-face teaching, she wanted to incorporate the dynamic, interesting pieces of the Quality Matters outlines into her course. Plus, she wanted to cover all the core concepts and core competencies outlined in *Vision and Change* (Woodin et al., 2012). Gonzales found that focusing on the key concepts of Vision and Change tended to incorporate the core competencies, seamlessly. A point of weakness was identified as a lack of student interactions. She went into depth on the methods used to assess the core competencies of *Vision & Change* in her course—reports, exams, quizzes, and discussions. This study seems directly relevant in the parallel focuses of the work, an online biology course and adherence to the *Vision & Change* backbone. Similar to our proposed Interview-Inquiry model, Gonzalez, used a post-semester Survey-Inquiry model to obtain her information on student perceptions.

The next focused study is one by Son, et al, (2016) at the California State Los Angeles campus. This paper states, "…the lab component should encourage students to investigate phenomena, solve problems, and pursue inquiry and interests in science." (p. 229) While this study does not specifically mention *Vision & Change*, the quoted sentence is directly parallel to the intent of the *Vision & Change* guidelines. In this study, the lectures remained face-to-face, but the laboratories were in three formats—all labs in person; all virtual labs with an in-person help center; or virtual labs and face-to-face labs in alternating weeks. The study authors examined the students' course grades and pre-and post-course surveys which tabulated a change in the students' attitudes towards biology which could be influenced by the course. Student grades were better in the alternating format with no significant difference in grades between the

face-to-face and all-online labs. Student attitudes toward biology improved in the alternating format. As with grades, attitudes improved most in the alternating format. The face-to-face labs did have an improved attitude toward biology; just not as dramatic as the alternating class did (Son et al., 2016).

The last biology-specific publication to discuss is a short article by Ofgang (2020). In this article, the authors discuss the use of online laboratories as a response to COVID-19's challenges for face-to-face education. He mentions some of the negatives associated with online laboratory courses. One question is will they disadvantage a student applying for graduate school or medical schools? Another negative is the question of hands-on techniques—can students truly learn a hands-on skill by watching someone else perform it? The author also offers positives to online laboratory offerings—as other online courses become more widely available, the sciences did not, also, have representative course offerings. Offering the courses in an online format is a necessary beginning if students would want to take them as online courses. The author, further, mentions ways to get the best online course experience, mentioning productive websites; suggesting hybrid models to include those in-person skills that cannot be replicated to a professor's comfort; and mentioning the availability of mailed at-home laboratory kits to supplement the virtual laboratory environment. This article spoke to the creative side of science educators. Yes, this was a challenge. Sometimes, challenges are what lead to innovation! (Ofgang, 2020)

Evaluation Methods

Multiple methods of assessing educational outcomes exist. One of these tools is described in a 2017 study by Durham, et al, using a Measurement Instrument for Scientific

Teaching (MIST), a survey that calculates the frequencies of which instructors mention particular practices aligning their teaching to a method referred to as the Scientific Teaching Method (Durham et al., 2017). Another option is the use of a knowledge survey, which aims to identify student confidence in their ability to answer a question—rather than necessarily seeing if they answer correctly (Bowers et al., 2005).

In Faulconer and Gruss's (2018) narrative review comparing online, remote, and distance science laboratories, they scored learning outcomes, "pedagogical, economic, and safety benefits and drawbacks for all permutations of a laboratory experience," (2018, p. 159) to collate data and develop suggestions for online course design. Their work concluded that non-traditional laboratories could be effective.

Options for evaluating a course's alignment with the *Vision & Change* recommendations are a rubric developed by the Partnership for the Undergraduate Life Sciences Education (Partnership for Undergraduate Life Sciences Education, 2015) which is aimed at departmental assessment of alignment or BioCore (Brownell et al., 2014), which is more aimed at course development than examining course effectiveness. Using these tools as guidelines, we have developed questions aligning closely with the core concepts of *Vision & Change* that can be delivered and examined as interview questions. These interviews will be presented to volunteer undergraduates at the completion of their online Introductory Biology laboratory course, while the information is still fresh and their impressions encapsulate a semester of activities and learning.

Consistent with Son's research and studies looking at *Vision & Change* in in-person and online laboratories, this research study employs an Interview-Inquiry Method to examine student perceptions of the online laboratories associated with Introductory Biology at a small, liberal arts

university. Questions are designed based on the Core Competencies, described by *Vision & Change* (AAAS, 2011), which are available for review in Appendix Table A1.

Summary

Biology students of today have resources that have changed how we approach their education. Memorization of terms and formulas have lost their prominence in the hierarchy of educational building blocks. Students can google the word that eludes them. Students can search for the background on their topic of choice. Students can query the explanation for the confusing variables in the equation with which they wrestle.

What they cannot search for is what we must now present. Instructors need to teach them the skills that help them become the critical thinkers we hope they become. Scientists think inquisitively and open-mindedly. Scientists question, examine, refute, and adapt. Those characteristics are innate but can be cultivated and honed into the precision instruments needed by a dynamic investigator.

It cannot be overstated that students still need to grasp the basic tenets of biology. They need to understand evolution, structure and function, information flow, pathways and transformation of energy, and systems. They need core competencies, a toolkit of skills they can utilize in their knowledge quests. See Appendix Table A1 to review the competencies. (Woodin et al., 2012). Instructors nurture and develop these skills in their students. Critical thinking skills are cultivated. Instructors in today's science disciplines want to tune the already present skills into the harmonic symphony they have the potential to be.

Can online education conduct this same composition?

How do the concepts established during the *Vision and Change* meetings translate to online education? While niche universities had explored online biology courses before, the COVID-19 pandemic was a catalyst for the conversion of programs, even in places priding themselves on their face-to-face biological educations. It was a time to adapt and adapt quickly. Keeping the focus on a 21st-century education with creativity, collaboration, critical thinking, and communication, educational innovators attempted to retrofit courses to include the best parts of hands-on laboratory experiences.

This research study assessed their creations. The setting was a small university in the Midwest with a commitment to a 4-year liberal arts education and a history of innovation and continuity. The research examined student perceptions of the online laboratories of an Introductory Biology course populated mainly by first-year students. The primary objective of the faculty of the Department of Biology and Earth Science was to encourage critical thinking in these developing scientists. Could the core competencies—as determined collaboratively by the AAAS and the NSF—be effectively taught using an online laboratory format? Would young scientists be fine-tuned, or would their education fall flat? Using an inquiry study, this research will initiate interviews to determine student perceptions of the online Introductory Biology laboratories. The study will answer the research question—using the Core Competencies framework from *Vision and Change*, what were student perceptions of the Online Introductory Biology laboratories.

Chapter 3
Methods

In this chapter, I will present my methods used to answer this question— Using the Core Competencies framework from *Vision and Change*, what were student perceptions of the Online Introductory Biology laboratories?

Research Methods

The research was performed at a 4-year private college in the Midwest. This university has a student body of 2,800, mostly undergraduate students, with graduate programs in Nursing, Education, Health Sciences, and Business. The university body makeup is 76% white, 6 % African American, 2% Hispanic, 2% Asian, and .3% Native American (Deloitte et al., 2014). The university is a liberal arts college with a history of innovation and inclusion, being a university on the forefront of having female faculty and students at its founding in 1847 and admitting African American students before the Civil War. The university is known for its strong Theatre, Music, Equine Science, and Nursing programs, with a thriving program in the Biological Sciences. This strong department has students majoring in Biology, Environmental Science, Zoo and Conservation Science, and Sustainability, with collaborative majors in Biochemistry and Molecular Biology as well as Environmental Health and Safety.

The Biology Department had 75 registered students within the major. The course in focus was Introductory Biology, Introduction to Molecular and Cell Biology. This course is the first in a two-course series typically taken in the freshman year. The course is taught with a three-day-a-week, one-hour lecture, accompanied by a one-day-a-week three-hour teaching

laboratory. The instructors are typically full-time faculty. During the semester in focus, the course was taught by a team consisting of an experienced full professor with a background in Immunology and Molecular Genetics and a new Assistant Professor with a background in Biological Anthropology and Conservation Genetics.

The student body of the course was made up of 29% self-identified male students and 71% female students. The ethnic self-identification of the students in the course was 78% Caucasian/White, 7% Black/African American, 5% Hispanic, 3% Asian, and 7% Two or more races. Grades attained by students in the course were 57% As, 25% Bs, 8% Cs, 4% Ds, and 5% Fs. Sample representation strength was analyzed using a Chi-Squared Goodness of Fit test (Appendix Table A1) to assess sample representative strength for gender, ethnic self-identification, and course grade. The twelve student-interviewees were found to be a strongly representative sample for gender, 17% male and 83% female, and course grade, 33% As, 50% Bs, 8% Cs, 8% Ds, and 0% Fs. The twelve student-interviewees were not found to be a strongly representative sample for self-identified ethnicity, 58% Caucasian/White, 0% Black/African American, 8% Hispanic, 17% Asian, and 17% Two or more races. By more limited categorization of ethnicities, this statistical deviation could have been eliminated, but no harm was seen from accepting the imperfect representation and maintaining the greatest number of ethnic identity categories.

The course syllabus for the online laboratory for Autumn of 2020 was compared to a course syllabus of in-person laboratories from Autumn of 2019 (Appendix Tables C1 and C2). While there were some deviations in topic and laboratory exercise, these deviations were no greater than could be expected with a new instructor contributing to a syllabus. There were similar numbers of weeks with breaks and similar numbers of weeks with computer-based topics.

The research study occurred in the fall semester of 2020, the beginning year of the COVID-19 pandemic's rampant growth in the United States. In response to the pandemic, many courses were available, often for the first time in their history, as online-only, or hybrid online-limited in-person courses. The research was conducted during the final four weeks of a fifteen-week semester and the subsequent winter break. In this course, both lecture and laboratory were offered online only, with the professors sharing teaching responsibilities for the lecture and laboratory. The course had two seventy-two-person lecture sections, with near-complete capacity, for a total of 141 students. The laboratories were divided into six twenty-four-person laboratory sections.

The laboratory exercise was filmed on Tuesday morning as the laboratory instructor presented an introduction to the week's topic followed by the filming of her performing the experiments. The professor would film the experimental procedure, film the data collection, and film a brief reflective conclusion to the day's video. Students were responsible for a prelab activity, and attendance was synchronous. The students would virtually meet up with the instructor for a live interactive opening. They would go over the prelab activities, which always included the development of a hypothesis of the dynamics of the day's experiment. The instructor would then start the experiment videos. At key points in the experiment, the instructor would stop the video to ask questions and interact with the students. At the conclusion of the video, students were placed in randomized breakout rooms of 2-4 students to collaboratively complete worksheets, analyze the experiment, discuss the day's data collection, and evaluate the data's support or refute of their hypotheses. The students would return to the electronic main meeting room for reflections and closing discussions, then dismiss for the day.

The researcher obtained permission from the instructors of the course to conduct the research. The university supplied an Institutional Review Board to examine the research proposal and determine the acceptability of the use of student interviewees. A consent document was included in the IRB proposal, and this consent would, later, be sent to and signed by, each student volunteering for the interviews.

Class lists were pulled for the two sections of lectures. Numbers from one to one hundred forty-one were assigned to the students to give them unique identifiers. Using the numerical assignments, the researcher used the website Random.org (Haarh & Ltd, 1998) to randomize the numbers. The researchers then began individually emailing the students to solicit volunteers, starting with the first fifteen random students, then adding on another ten students every two to three days until thirteen volunteers had been identified. (See Appendix Table A2)

After receiving positive interest from the volunteers, the researcher replied with an email thanking them for volunteering. The email included a list of available interview times, requesting that they choose a convenient time for a virtual interview. The email included a link for a secure Blackboard Ultra meeting room, set up by the interviewer. The email also included the consent form, a request for the student to read the consent form and ask any questions, and a request for the student to sign the consent form and return it to the researcher or to virtually sign the consent form by emailing a consent statement to the researcher, acknowledging having read and approved the consent.

Students and interviewer met, virtually, in the Blackboard Ultra meeting room. The researcher asked the students a series of nine questions adapted from the Core Competencies of the *Vision and Change* report (Chapter 4, Table 1). The first Core Competency, "Exposure to Scientific Thinking" was evaluated by four separate questions to determine their comfort with

the concept of Scientific Theory and their personal experience with developing, testing, and evaluating hypotheses.

The researcher took hand-written notes, and also recorded the interviews for complete transcription. There were technical difficulties in several cases, at which time the researcher and student used the "Chat" option to write the questions and answers to one another. This allowed for copy and pasting the answers for submission.

Transcriptions were made by playing the video recordings and using the "Voice Typing" feature of Google Docs to create a rough transcription. The researcher heavily edited the documents to add punctuation, spacing, and wording corrections.

Students were contacted for a secondary group interview to allow them to discuss the accuracy of the students' answers and to allow the students to hear others' answers and inspire elaborated answers, retractions, or new lines of thinking. These interviews were recorded. The second interviews were then transcribed using the previously described methodology. The intention was for all students to participate in two interviews, but only six students scheduled and attended the second interviews.

The researcher looked at the answers from interviews one and two and analyzed the data for patterns, themes, and outliers (Mertler, 2019). Before analyzing the data, the researcher assigned each student a gender-neutral pseudonym to mask their identity for analysis, publication, and information dissemination. The twelve pseudonyms assigned were Alex, Benny, Chris, Danny, Frankie, Gale, Jamie, Kelly, Lou, Max, Nick, and Pat.

The students' responses were scored with a simple categorization system. If the student answered negatively or with "I cannot remember" or "I cannot recall" or a variation on that, the

answer was scored a “2”. If the student answered affirmatively and mentioned a specific lab or lesson but did not attach any enthusiastic elaboration to the description, the answer was scored a “3”. If the answer mentioned “worksheets”, it was scored a “4”. If the answer mentioned “Breakout rooms” by name, it was scored a “5”. Students who mentioned other communication methods were not scored a “5”, but were, rather scored with a “1”, which will be described later in this paragraph. If the student answers mentioned the course’s synchronous nature, with the professor being present and dynamic during the hours in which the students were meeting virtually, the answer was scored a “6”. If the students mentioned one of the three human-interest, relevant lessons which they described with elaboration and enthusiasm, the answer was scored a “7”. These lessons were the Human Genome Laboratory, the COVID-19 laboratory, and a lecture on Gender and Genetics. If the response was affirmative—whether it was brisk or elaborate—but did not specifically mention a particular lab, worksheets breakout rooms, synchronous nature, or the three distinguished lessons being labeled the Human-Interest lessons, the response was scored a “1”.

Table 1. Scoring categories for student responses

1=General affirmative
2=No recollection or answers in negative
3=Mentions a particular lab or example in affirmative
4=Mentions worksheets
5=Mentions Breakout rooms
6=Mentions synchronous nature
7=Mentions a human-interest lesson as special

The Inquiry-Interview study format was selected as the best way to allow students to answer the questions and have the opportunity to elaborate and freely speak. The interview format is supported in educational research (Mertler, 2019) and sociological research

(Blackstone, 2012) as being a strong qualitative research method for that open framework allowing for elaboration. Interviews allow for surprising answers that the researcher may not have foreseen.

Limitations of the Research

A limitation of the Interview-Inquiry format can be identified within the researcher's analysis of interview data, as the data is qualitative in nature. The use of coding to make data analysis consistent negates some of this challenge. In this research study, the data coding seemed to characterize and categorize the data effectively.

A limitation of any research dependent on volunteers is selection bias. Students who want to volunteer will volunteer. No sample can ever be completely random, if the "non-volunteering types" have the freedom to opt out. Committed to freedom to volunteer or not, the researcher can minimize this effect to the best of his or her ability. In this research study, the volunteer solicitations were randomized. While the randomization's effectiveness was marginalized by the low number of respondents, the effort was made. The sample representativeness was shown by statistical analysis to be within an acceptable bound for both gender and grades, and very close to within bounds for self-identified ethnicity. With no identified method for statistically testing the "volunteer"-propensity of students, there is no verifiable way to say the volunteers were outside the boundary, nor within. The researcher has done due diligence in this regard, within the ability of a well-intentioned researcher.

Other limits of the Interview-Inquiry format exist. One is that the answers are dependent on student interpretation of the questions and upon student recall. Students also could have a propensity for trying to please the researcher, with an inclination to give positive responses. Having a secondary interview, with other students present and an informal setting could,

potentially, negate this initial response, as one negative-toned answer could enact a sense of freedom to be candid. The secondary interview also encourages more comfort with the interviewer which could encourage forthrightness. The benefit of students being allowed to speak in stream-of-consciousness format is of value, as will be seen in the Analysis and Conclusion area of this research paper. It was this researcher's view that the free-speak of an interview format outweighed the limitations posed by an interview format.

Chapter 4
Results

Twelve student respondents answered questions framed from the core competencies of the *Vision & Change* recommendations. Students' answers were insightful as the students reflected on their experiences in a semester of online Introductory Biology. Representative transcripts are available in Appendix Transcripts B1, B2, and B3.

Table 2. Questions designed from the Vision and Change Core Competencies

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?
2. Can you tell me about times when the online laboratory format gave you practice in formulating hypotheses?
3. Can you tell me about times when the online laboratory format gave you practice in testing hypotheses experimentally or observationally?
4. Can you tell me about times when the online laboratory format gave you practice in analyzing experimental or observational results?
5. Can you tell me about times when the online laboratory format gave you an exposure to quantitative reasoning?
6. Can you tell me about times when the online laboratory format gave you an exposure to Modeling and simulation?
7. Can you tell me about times when the online laboratory format gave you an exposure to the interdisciplinary nature of science?
8. Can you tell me about times when the online laboratory format gave you an exposure to Communication and collaboration?
9. Can you tell me about times when the online laboratory format gave you an exposure to the relationship between science and society?

Questions One Through Four

The first four questions were similar to one another in nature, trying to tease out students' recognition and comfort with a key tenet of science, the hypothesis. Did students understand that the testing of a hypothesis was a cornerstone of scientific thinking, and had they been exposed to formulating and testing hypotheses through their online laboratory experience? There were times when I regretted keeping the similarity of the questions, when the students would seem frustrated that I was repeating the same question. I would try to then accentuate whichever words were being highlighted in that particular question, with varying degrees of forgiveness and returning to enthusiasm by the students.

The first question used the term "scientific method" to assess familiarity with the term. Eleven of the twelve students were familiar with the term and were able to give single or multiple examples of it in the context of specific laboratory lessons. An exemplary response was given by Max, who said, "Every single one of the labs. We did worksheets during and after the labs, and each one had a 'predictions' area." While "predictions" are not the same thing as hypotheses, there is a relation. "A hypothesis is a potential explanation for a phenomenon (a "why"), and an experiment is designed to test that explanation. A prediction has to do with the expected outcome of a particular experiment or event (a "how"), and this prediction may or may not be connected to a hypothesis," as explained by Dr. Paul Wendel, a professor of Science Education in Ohio. The scientific method is the formulation of hypotheses to explain a phenomenon, then the careful design of experimentation to test that hypothesis. Upon data refuting the hypothesis, another hypothesis is formed, building on the acquired knowledge. This is a complex and methodical method of honing in on truth in science and systems.

Table 3. Question 1 Answers Categorized

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
6	3	3,6	1	2	6	3	3	1	4	6	1
3	1=General affirmative										
1	2=No recollection or answers in negative										
4	3=Mentions a particular lab or example in affirmative										
1	4=Mentions worksheets										
0	5=Mentions Breakout rooms										
4	6=Mentions synchronous nature										
0	7=Mentions a human-interest lesson as special										

The second question was to highlight if the students recalled formulating hypotheses for themselves. To this question, I received multiple quizzical looks and responses of, “The same labs I just described in Question 1.” Students mentioned specific labs for which they formulated a hypothesis. But they also began to mention something else. Alex, Gale, Lou mentioned the worksheets, as Max had to that first question. All three mentioned the worksheets, as having a consistent requirement of formulating a hypothesis. Quizzes were also mentioned for the first time, by Lou, who said, “Whenever we did our quizzes, when we went into the breakout labs, the quizzes would always as for our opinion. That was also in the worksheets, too. There was always an area.” In this case, I would conjecture that “opinion” was being used interchangeably with “prediction”, but that is a conjecture. The worksheets would be a surprising and repeated theme of import throughout the interviews.

Table 4. Question 2 Answers Categorized

2. Can you tell me about times when the online laboratory format gave you practice in formulating hypotheses?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
4	3	1	3	3	4	3	3	4,5	4	6	2
1	1=General affirmative										
1	2=No recollection or answers in negative										
5	3=Mentions a particular lab or example in affirmative										
4	4=Mentions worksheets										
1	5=Mentions Breakout rooms										
1	6=Mentions synchronous nature										
0	7=Mentions a human-interest lesson as special										

Question three was where the students first expressed a sense of melancholy, if that term can be afforded to a question about a science course. The question asked if the laboratory format gave students practice in testing hypotheses experimentally or observationally. Benny stated, "We didn't get to test our own, because we weren't doing the labs by hand." Max's view was similar, "Observationally, way more if not completely. The professor would show us the videos and we made our observations from there." Likewise, for Gale, "It was definitely observing the hypothesis being tested." This was the first flicker of discontent with the disconnect experienced from online labs. For the most part, the student responses tended to be positive and content.

Table 5. Question 3 Answers Categorized

3. Can you tell me about times when the online laboratory format gave you practice in testing hypotheses experimentally or observationally?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
1	2	6	1	2	1	3	3	4	6	6	3
1	1=General affirmative										
2	2=No recollection or answers in negative										
3	3=Mentions a particular lab or example in affirmative										
1	4=Mentions worksheets										
0	5=Mentions Breakout rooms										
3	6=Mentions synchronous nature										
0	7=Mentions a human-interest lesson as special										

Question four was similar to question three. Its focused goal was to ask for times when students had practice in analyzing experimental or observational results. Many of the respondents mentioned particular lab exercises where they were presented results to view. Multiple students mentioned a particular lab, the yeast mutagenesis 3-part lab, as a good example of this data presentation for analysis. As Chris explained, "During the yeast lab, the pictures were there,"… "We had to break it down and explain what was going on during the laboratories." Other students answered question four with a more generalized evaluation. Danny answered in this manner, “Yes, we look over questions and stuff and discuss our results. We discuss what we saw.”

Table 6. Question 4 Answers Categorized

4. Can you tell me about times when the online laboratory format gave you practice in analyzing experimental or observational results?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
4	1	3	1	3	1	3	3	3	6	6	3
3	1=General affirmative										
0	2=No recollection or answers in negative										
6	3=Mentions a particular lab or example in affirmative										
1	4=Mentions worksheets										
0	5=Mentions Breakout rooms										
2	6=Mentions synchronous nature										
0	7=Mentions a human-interest lesson as special										

Question Five

Question five broke us out of our "frustration" zone, which is how the students seemed to view the first four questions sounding quite similar. With question five, we introduced a distinguished new topic, quantitation. I would ask the question, then, always, elaborate on the term "quantitative", by adding, "numerical" or "mathematical" as similar terms. Alex responded with, "Yeast mutagenesis lab was highly quantitative. There was a high amount of math," Alex added, "There were a few labs," when we went over answers during a follow-up interview. Chris's answer had a similar feel, "During the yeast lab, we calculated colonies. In the COVID lab, there were many quantitative calculations, figuring out if a person was infected." Chris reinforced this answer during the follow-up interview, adding, "Definitely, there was quantitative analysis in the yeast and COVID labs. Also, in the Human Genome Lab, we worked in populations." Having a defined focus seemed to help this question get solid responses.

Table 7. Question 5 Answers Categorized

5. Can you tell me about times when the online laboratory format gave you an exposure to quantitative reasoning?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
3	3	3	3	3	1	3	1	3	3	3	3

2	1=General affirmative
0	2=No recollection or answers in negative
10	3=Mentions a particular lab or example in affirmative
0	4=Mentions worksheets
0	5=Mentions Breakout rooms
0	6=Mentions synchronous nature
0	7=Mentions a human-interest lesson as special

Question Six

Question six asked for times when the online laboratory format gave students exposure to modeling and simulation. About halfway through the interviews, I began to wonder if this term also needed some clarification. At that time, I began making sure I had a definition of "Modeling and Simulation" visible on my computer screen, available to read as a consistent prompt. This sentence from Wikipedia was what I kept accessible, "Modeling and simulation is the use of models as a basis for simulations to develop data utilized for managerial or technical decision making,"(Wikipedia Contributors, 2020). Answers to this question were more diffuse. "In the yeast experiment, one ball of yeast was many colonies," was Nick's response. Chris mentioned, "In the strawberry DNA lab, we took the idea of a DNA strand being so long and spread out and made it visual. It took the ideas we were looking at. There was a simulation in the video, then we saw the same during lab itself." A majority of the students mentioned the computer-based labs focusing on the Human Genome or COVID, as fitting their perception of a simulation.

Table 8. Question 6 Answers Categorized

6. Can you tell me about times when the online laboratory format gave you an exposure to Modeling and simulation?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
3	3	3	3	2	3	3	3	3	3	3	3
0	1=General affirmative										
1	2=No recollection or answers in negative										
11	3=Mentions a particular lab or example in affirmative										
0	4=Mentions worksheets										
0	5=Mentions Breakout rooms										
0	6=Mentions synchronous nature										
0	7=Mentions a human-interest lesson as special										

Question Seven

Question seven explored the students' exposure to the interdisciplinary nature of science. The students were enthusiastic about answering this one. Lou stated, "All labs would overlap with Math—a few of them. One overlapped with Chemistry, and I recognized it from a Chem lecture." Gale said, “Many times, we would discuss morals and biology. I think Henrietta Lacks. There were many alignments with Chemistry. Many times, it was ‘Science, but why Science?’.” Kelly answered the same question with, “Mathematics, statistics, and chemistry were all used to explain why the actions happened.”

Table 9. Question 7 Answers Categorized

7. Can you tell me about times when the online laboratory format gave you an exposure to the interdisciplinary nature of science?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
7	3	6	7	3	3	7	1	1	3	1	3
3	1=General affirmative										
0	2=No recollection or answers in negative										
5	3=Mentions a particular lab or example in affirmative										
0	4=Mentions worksheets										
0	5=Mentions Breakout rooms										
1	6=Mentions synchronous nature										
3	7=Mentions a human-interest lesson as special										

Question Eight

If a researcher was allowed to have a favorite question, mine would have been question eight. It is not because of the question itself, but, rather, due to the surprise and insightfulness of the students' answers. In a year where they were overcoming the shock of imposed separation and isolation, their answers were reflective of late-teens and early-twenties students accepting connection when it was offered. The question asked, “Can you tell me about times when the online laboratory format gave you an exposure to communication and collaboration?” Alex’s answer to the question picks up on multiple themes which I will examine in the “Analysis” area of this chapter. “We were in many breakout groups. They would show us a video or lab, and we would go into breakout groups and work in groups to answer the questions. They did a good job of including collaborating in every lab and lecture.” Gale stated, “Yes, were put into breakout groups at least twice per lab. Randomized groups. Many times, to ask for insight into what was going on." As Max also observed, "Every lab, we were put in breakout labs and worked on worksheets. It was very helpful. Without teamwork, I wouldn't have made it through."

Summarily, of the twelve first-round interviews, eight of them mentioned breakout rooms by name as giving them a feeling of collaboration. One student, Frankie, mentioned breakout rooms implicitly, without using the word "breakout room". Nick described the professor's quick problem-solving when faced with technical difficulty, instantly having the students use a messaging box or email as a replacement. Kelly said, very positively, "Yes, it was a lot easier when a lab failed, and you had time to meet up and discuss it. We would, independently, arrange to meet up at the library and actually see each other." You could tell this was a pleasurable

meeting for Kelly. It was the happiest I had heard of a student or professor ever describing the results of a failed lab.

The only one to point out something still missing was Jamie, who stated, “We didn't really ‘collaborate’ with other students. It was mostly us pupils watching videos of them doing the lab and just copying answers they said to us. To me, it was a very ineffective way to learn and absorb information. I didn't retain any important information, but rather just gave the correct answers that I consciously absorbed for a short parameter of time that the Professor fed me. I'm a very visual learner, so that's how I learn best,” (See Appendix B3). Jamie was not, necessarily, referring to a lack of any collaboration, but was pointing out that the lack of face-to-face interaction and the sense of disconnect experienced did affect learning.

Table 10. Question 8 Answers Categorized

8. Can you tell me about times when the online laboratory format gave you an exposure to Communication and collaboration?											
Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
5	5	5, also chat group	1, talking but not specifically breakouts	1	5	2	1, meeting in library to work through failed labs	4,5	4,5	1, if kicked off wifi, message or email	5
4	1=General affirmative										
1	2=No recollection or answers in negative										
5	3=Mentions a particular lab or example in affirmative										
2	4=Mentions worksheets										
7	5=Mentions Breakout rooms										
0	6=Mentions synchronous nature										

Question Nine

The last of the nine questions asked about experiencing an exposure to the relationship between science and society. Across the twelve students' answers, there were three specific lessons echoed with no prompting beyond the researcher asking the question. Seven students mentioned the COVID genetics and epidemiology laboratory. Four students mentioned the human genome laboratory that discussed skin pigmentation and the genetic and societal representations of racial identity. The last of the three lessons mentioned was a topic discussed in lecture only, a gender discussion.

Table 11. Question 9 Answers Categorized

9. Can you tell me about times when the online laboratory format gave you an exposure to the relationship between science and society?

Alex	Benny	Chris	Danny	Frankie	Gale	Jamie	Kelly	Lou	Max	Nick	Pat
7	7	7	7	2	7	1	7	7	7	7	7

1	1=General affirmative
1	2=No recollection or answers in negative
0	3=Mentions a particular lab or example in affirmative
0	4=Mentions worksheets
0	5=Mentions Breakout rooms
0	6=Mentions synchronous nature
10	7=Mentions a human-interest lesson as special

Chapter 5
Analysis and Conclusions

Analysis of the students' answers was eye-opening and insightful. The students' recollection of the laboratories and their introspection about which aspects had value to them was a source of joy. As components of value were mentioned repeatedly by differing students, the researcher's confidence in the student reflections rose substantially. Using the Core Competencies framework from *Vision and Change*, what were student perceptions of the Online Introductory Biology laboratories?

This first theme of the students' answers was that most recognized the scientific method as being intrinsic to each laboratory. The students formed predictions of what they thought would occur during the laboratory at the beginning of each session, directly following the instructor's introduction but before students watched the laboratory exercise being executed on video. The students were to formulate a hypothesis to explain why the events would occur. This sounds like the hypotheses-formulation occurred within a no-pressure environment, enabling students to not feel vulnerable to ridicule if the hypothesis was not supported by the experimental results.

The students' next point of mention was that the professor continued to be present and interactive, which was mentioned by three separate students and discussed in depth by Chris who mentioned in multiple answers the professor stopping the video to talk and ask them questions. The professor would give them a moment to predict what would occur next in an informal, low-pressure format. Even though the laboratory experiment was only filmed a single time, during the first laboratory of the week, the professors synchronously presented each laboratory to their

students. The professors played the video of the experiment being executed but would stop the video to ask a question or highlight a moment of importance. These moments kept the students engaged, and gave them the knowledge that their professors were still present and engaged. This appeal of the synchronous meeting was consistent with the findings of

Two students mentioned reflections about work done before the lab, whether as an assignment to pre-read or an actual pre-lab assignment. The students mentioned these as having introduced the topic and established initial familiarity.

Worksheet assignments were mentioned at different times by multiple students. They listed the worksheets as places where they began to think of their hypotheses, and one student even mentioned that they were working with a null hypothesis that they had written. More often, the worksheets were mentioned as an important impetus to the collaboration and group work that they seemed to relish. Students said they enjoyed the breakout rooms and the encouragement to work together on the worksheets. Gale mentioned liking the "randomized" groups for this work so that there was interaction with multiple students. The worksheets required some effort and thought but were not beyond comprehension, comfortably within Vygotsky's Zone of Proximal Development (Woolfork, 2017). The students were able to contribute to the group's work. This is consistent with the findings of Weir, et al in their 2019 study looking at teaching practices (Weir et al., 2019). They described worksheets as collaborative. They found them to be a good formative assessment. They found that they had a positive impact on diagnostic test scores. They found the group work predicted learning gains. All of these descriptors were found by my research to be highly relevant to students' perceptions of their online experiences. Considering that many of these students were in their first semester of college, which they had entered during the early months of a pandemic, navigating these formative bonding experiences in an online

environment, having low-stress, dependable worksheet to turn to as a catalyst for interacting with their new peers was invaluable.

The collaborative experience of the worksheets ties in with the next identified theme, which was the breakout rooms themselves. I will, again, remark on the appreciation for the randomization of the groups, which eliminated the need to already have a clique. Students needed to have introductory interactions with their new peers. The breakout rooms, with their intimate dynamic and their low-pressure setting, gave the students social connection and a safe space to voice their views, a place to hear others' interpretations, and a place to have moments of disequilibrium and re-learning. They were described as a place where "…we were allowed to talk to one another and discuss the questions." Students identified the breakout rooms, separate from their discussions of worksheet collaboration, as being "easier to meeting their classmates in these settings," in the words of the student, Lou.

The last theme I will mention was something that has been discussed by excellent teachers in different domains. The students would have described this phenomenon as having "topics of interest", but educators would go deeper and conclude the students were describing events of disequilibrium, Piaget's theory described in Chapter 2 of Educational Psychology by Woolfork (Woolfork, 2017). The American Psychological Association Dictionary of Psychology defines disequilibrium as "in developmental psychology, a state of tension between cognitive processes competing against each other. In contrast to Jean Piaget, some theorists believe that disequilibrium is the optimal state for significant cognitive advances to occur,"(American Psychological Association, 2020). As Harackiewicz, et al, found in their 2016 research, interest in a topic can make a vast difference in a student's educational outcomes. "Interest is a powerful motivational process that energizes learning, guides academic and career

trajectories, and is essential to academic success. Interest is both a psychological state of attention and an affection toward a particular object or topic, and an enduring predisposition to reengage over time. …Promoting interest can contribute to a more engaged, motivated, learning experience for students," (Harackiewicz, J. M., Smith, J. L., & Priniski, 2016).

The students in this study mentioned three lessons that they found engaging and engrossing. During their descriptions, they offered key things they had learned or found "new", which I categorize as their Human-interest lessons. The students mentioned the COVID-epidemiology laboratory exercise and appreciated the depth at which it was discussed, including looking at effects on mental health. The second topic mentioned was a Human Genome laboratory that discussed skin pigmentation and the societal and physiological viewpoints on race. Students were excited to talk to me about the things they had been taught which surprised them. In educational psychology, those "surprises" are moments of students experiencing disequilibrium. The same sense of excitement came from their discussions of Gender that were covered in the lecture part of the course. Despite it not being a part of the laboratory, which this research focused upon, the students wanted to talk about the exciting, new things they had learned about the genetics and physiological intricacies of gender. Even one student who self-identified discomfort with the topics, stating that she felt these topics were trying to sway her from religious beliefs with "opinion-laced lectures" mentioned these same three subjects. The students' engagements in these topics seemed noteworthy. Whether drawn to the topics or offended by the topics, the students were engaged. In a 2020 opinion blog for EdWeek, Larry Ferlazzo moderated a discussion with educators titled, "Ways to Make Lessons 'Relevant' to Students' Lives" in which six educators delved into the idea that "one key way to encourage

intrinsic motivation to learn is by making classroom lessons relevant to students' lives," (Ferlazzo, 2020). What students care about, they want to explore.

To summarize and conclude, students were exposed to the core competencies that the National Academy of Sciences and the American Association for the Advancement of Science viewed as key skills needed to be in the arsenal of our up-and-coming generation of scientists. The laboratory portion of a private liberal arts university in a mid-sized city in Ohio met the criteria. But the research did not look at how this was handled in a typical, ideal, hands-on laboratory course. During the 2020 autumn semester, this and many courses were completely online. Were the instructors able to guide their students through these core competencies in an online laboratory environment? There were some students who did not identify places where all the criteria were met. That is true. For the most part, each of the twelve representative students interviewed to assess their views was able to identify ways that they were instructed in these core competencies.

Why is this relevant? Educational studies (Wyzant, 2021) and mainstream media stories (Morse, 2021) are reporting students falling behind educationally due to remote learning. Knowing that science is viewed as something best learned through hands-on, inquiry-based classrooms, were the instructors able to keep their students on-task and deliver the competencies to keep these students on track educationally? It appears that they were able to succeed.

What were student perceptions of the online introductory laboratories? Students reported mostly positive views of their online experience. They credited the instructors with giving them time to meet and collaborate with new peers. They appreciated being given a straightforward and conquerable task, in the state of a worksheet, which they worked with their peers. They appreciated the synchronous learning format of the professors, touting the experience of the

professor remaining engaged and bringing key points and questions to the students' attention. The students highlighted favorite (or least favorite) topics like those that made them the most surprised or those that were directly relevant to their present-day experiences. The instructors, guiding them through the science of difficult topics, were acknowledged and appreciated locally. The student summaries of their viewpoints were, overall, quite positive.

Further research in this area could delve into comparing student experiences in wide-ranging subjects. Were the experiences of these budding scientists affected by the fact they were studying a course within their major of interest? Or were the students' focal topics—the synchronous teaching styles and the use of breakout rooms—more focused on those particular course attributes than being dependent on the topic of the course?

Knowing the limited interactions that on-campus students were recommended to be having, especially during the earliest weeks of returning to campus during a pandemic, did their online classmate bonds suffice to give them the needed socialization so important to humans of all ages? Did those bonds lead to the friendships we associate with the freshman year of a college experience? And were retention rates higher for students reporting positive online bonding experiences?

The key concepts of *Vision & Change* (Appendix Table A1) were touched on during the schedule of Introductory Biology lessons, with the intentional design of the instructors. To incorporate evolution, systems, the flow of information, transformation of energy, and interrelatedness of organisms, the instructors had to creatively design laboratories suited to a video-recorded format that would touch on each topic, often returning to previous discussions and building on educational foundations laid in earlier weeks. The core competencies of the blossoming scientists, (Appendix Table A1) were developed by incorporating these skills into

the format of the weekly lessons, with hypothesis formation and evaluation being anticipated steps upon which the students could depend. The breakout rooms and worksheets provided predictable, comfortable collaborative time. Quantitative reasoning was scaffolded, with instructors being present in synchronous lessons to assist with questions or provide prompts. Interdisciplinary work and societal relevance were thematically present throughout the semester.

These students were so forthright in their answers given to an educational researcher. With their attitudes of appreciation and adaptability, there are some resilient scientists in the training pipeline this year. If we have done right by them, and gotten across the skillsets they will need to continue to develop, I have complete faith that these students will have the initiative to see their aspirations through to completion.

References

Academic Partnerships for the Future of State Universities. (n.d.). *Research on the Effectiveness of Online Learning A Compilation of Research on Online Learning*. http://www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf

American Association for the Advancement of Science. (2011). *Vision and Change: In Undergraduate Biology Education - A call to action*.

American Chemical Society. (2017). *Importance of Hands-on Laboratory Science.* https://www.acs.org/content/acs/en/policy/publicpolicies/education/computersimulations.html

American Psychological Association. (2020). *Definition of Disequilibrium*. Online Dictionary of Psychology. https://dictionary.apa.org/disequilibrium

Blackstone, A. (2012). Interview Research: What is it and when to use it. In *Principles of Sociological Inquiry: Qualitative and Quantitative Methods* (pp. 9.1-9.4). Sayler Academy. https://saylordotorg.github.io/text_principles-of-sociological-inquiry-qualitative-and-quantitative-methods/index.html

Bowers, N., Brandon, M., & Hill, C. D. (2005). The use of a knowledge survey as an indicator of student learning in an introductory biology course. *Cell Biology Education*, *4*(Winter), 311–322. https://doi.org/10.1187/cbe.04-11-0056

Brownell, S. E., Freeman, S., Wenderoth, M. P., & Crowe, A. J. (2014). BioCore Guide: A tool for interpreting the core concepts of vision and change for biology majors. *CBE Life Sciences Education*, *13*(2), 200–211. https://doi.org/10.1187/cbe.13-12-0233

Castro, M. D. B., & Tumibay, G. M. (2019). A literature review: Efficacy of online learning courses for higher education institution using meta-analysis. *Education and Information*

Technologies, 1–19. https://doi.org/10.1007/s10639-019-10027-z

Cirulli, F., Elia, G., Lorenzo, G., Margherita, A., & Solazzo, G. (2016). The use of MOOCs to support personalized learning: An application in the technology entrepreneurship field. *Knowledge Management and E-Learning*, *8*(1), 109–123.

College Board. (2020). *AP Biology Curriculum Framework*. https://apcentral.collegeboard.org/courses/ap-biology/course

Deloitte, Datawheel, & Hidalgo, C. (2014). *DataUSA_Otterbein University*. DataUSA. https://datausa.io/profile/university/otterbein-university

Durham, M., Couch, B., & Knight, J. (2017). Measurement instrument for scientific teaching (Mist): A tool to measure the frequencies of research-based teaching practices in undergraduate science courses. *CBE Life Sciences Education*, *16*(4), 1–14. https://doi.org/10.1187/cbe.17-02-0033

edX.org. (2019). *Massive Open Online Courses (MOOCs)*. https://www.mooc.org/

Faulconer, E., Griffith, J., Wood, B., Acharyya, S., & Roberts, D. (2018). A comparison of online, video synchronous, and traditional learning modes for an introductory undergraduate Physics course. *Journal of Science Education and Technology*, *27*(5), 401–411. https://doi.org/10.1007/s10956-018-9732-6

Faulconer, E. K., & Gruss, A. B. (2018). A review to weigh the pros and cons of online, remote, and distance science laboratory experiences. In *International Review of Research in Open and Distributed Learning* (Vol. 19, Issue 2).

Ferlazzo, L. (2020). *Ways to Make Lessons "Relevant" to Students' Lives*. EdWeek Opinion Blog. https://www.edweek.org/teaching-learning/opinion-ways-to-make-lessons-relevant-to-students-lives/2020/05

Feynman, R., Leighton, R., & Sands, M. (2013). *The Feynman Lectures on Physics*. Caltech Division of Physics, Mathematics, and Astronomy. https://www.feynmanlectures.caltech.edu/

French, D. (2012). From the President. *American Biology Teacher*, *74*(8), 536–537. https://doi.org/10.1525/abt.2012.74.8.1

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research*, *82*(3), 300–329. https://doi.org/10.3102/0034654312457206

Gonzalez, B. (2016). Time for action: Vision and Change implementation in an online Biology course at a community college. *Journal of College Science Teaching*, *45*(4), 15–21. www.biologycorner.com/

Gregory, E., Ellis, J. P., & Orenstein, A. N. (2011). A proposal for a common minimal topic set in introductory biology courses for majors. *American Biology Teacher*, *73*(1), 16–21. https://doi.org/10.1525/abt.2011.73.1.4

Haarh, M., & Ltd, R. and I. S. (1998). *True Random Numbers*. https://www.random.org/

Harackiewicz, J. M., Smith, J. L., & Priniski, S. J. (2016). Interest matters: The importance of promoting interest in education. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 220–227. https://doi.org/10.1177/2372732216655542

Heppen, J., Sorensen, N., Walters, K., Rickles, J., Taylor, S., Allensworth, E., & Michelman, V. (2017). The struggle to pass Algebra: Online vs. face-to-face credit recovery for at-risk urban students. *Journal of Research on Educational Effectiveness*, *10*(2), 272–296. https://doi.org/10.1080/19345747.2016.1168500

Jardine, H., Levin, D., Quimby, B. B., & Cooke, T. (2017). Group active engagement exercises:

Pursuing the recommendations of Vision and Change in an introductory undergraduate science course. *Journal of College Science Teaching*, *046*(05), 20–26. https://doi.org/10.2505/4/jcst17_046_05_20

Little, M. D. (2013). Embrace Vision & Change. *American Biology Teacher*, *75*(6), 368. https://doi.org/10.1525/abt.2013.75.6.1

Lysne, S., & Miller, B. (2015). Two-year community: Implementing Vision and Change in a community college classroom. *Journal of College Science Teaching*, *044*(06), 11–16. https://doi.org/10.2505/4/jcst15_044_06_11

Maryland Online Consortium. (2020). *Standards from the QM Higher Education Rubric*. https://www.qualitymatters.org/sites/default/files/PDFs/StandardsfromtheQMHigherEducationRubric.pdf

McLaughlin, J., & Metz, A. (2016). Vision & Change: Why it matters. *The American Biology Teacher*, *78*(6), 456–462. https://doi.org/10.1525/abt.2016.78.6.456

Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2010). *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies Center for Technology in Learning*. www.ed.gov/about/offices/list/opepd/ppss/reports.html.

Mertler, C. A. (2019). Interviews and Surveys. In K. Omer (Ed.), *Introduction to Educational Research* (2nd Editio, pp. 169–170). SAGE Publications, Inc.

Miller, T., Carver, J., & Abhik, R. (2018). To go virtual or not to go virtual, that is the question: A comparative study of face-to-face versus virtual laboratories in a physical science course. *Journal of College Science Teaching*, *48*(2), 59–67.

Morse, C. (2021, February 9). New information shows students in Ohio might be falling behind.

2News Wdtn.Com. https://www.wdtn.com/news/local-news/new-information-shows-students-in-ohio-might-be-falling-behind/

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. In *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. https://doi.org/10.17226/13165

Nguyen, T. (2015). The effectiveness of online learning: Beyond no significant difference and future horizons. *MERLOT Journal of Online Learning and Teaching*, *11*(2), 309–319.

Ofgang, E. (2020). Online Labs Are Higher Ed's Latest Experiment Like true scientists, college instructors are trying new approaches to online labs to provide hands-on learning opportunities. *STEM & Emerging Tech*, *October*, 22. www.techlearning.com

Partnership for Undergraduate Life Sciences Education. (2015). *The PULSE Vision & Change snapshot rubric version 2.0*. https://pulse-community.org/sites/default/files/PULSESnapshotRubricPacket2.0.pdf

Partnership of the Future of State Universities. (2011). Research on the effectiveness of online learning - A compilation of research on online learning. In *The Future of State Universities*. http://www.academicpartnerships.com/research/white-paper-research-in-online-learning

Quality Matters Association. (2020). *Quality Matters Course Design Rubric*. 6th Edition. https://www.qualitymatters.org/qa-resources/rubric-standards/higher-ed-rubric

Rowe, R. J., Koban, L., Davidoff, A. J., & Thompson, K. H. (2018). Efficacy of online laboratory science courses. *Journal of Formative Design in Learning*, *2*(1), 56–67. https://doi.org/10.1007/s41686-017-0014-0

Schroeder, C. M., Scott, T. P., Toison, H., Huang, T. Y., & Lee, Y. H. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the

United States. *Journal of Research in Science Teaching*, *44*(10), 1436–1460. https://doi.org/10.1002/tea.20212

Simcock, D. C., Chua, W. H., Hekman, M., Levin, M. T., & Brown, S. (2017). A survey of first-year biology student opinions regarding live lectures and recorded lectures as learning tools. *Advances in Physiology Education*, *41*(1), 69–76. https://doi.org/10.1152/advan.00117.2016

Son, J., Narguizian, P., Beltz, D., & Desharnais, R. (2016). Comparing physical, virtual, and hybrid flipped labs for general education biology. *Online Learning Journal*, *20*(3). https://doi.org/10.24059/olj.v20i3.687

Tom. (2017). *The History of Online Education*. Peterson's. https://www.petersons.com/blog/the-history-of-online-education/

Trilling, B., & Fadel, C. (2009). *21st Century Skills, Learning for Life in our Times*. Jossey-Bass/Wiley.

Vanmali, B. (2014). *Biology Education Reform at Arizona State University*.

Weir, L. K., Barker, M. K., McDonnell, L. M., Schimpf, N. G., Rodela, T. M., & Schulte, P. M. (2019). Small changes, big gains: A curriculum-wide study of teaching practices and student learning in undergraduate biology. *PLoS ONE*, *14*(8), 1–16. https://doi.org/10.1371/journal.pone.0220900

Wikipedia Contributors. (2020). *Modeling and Simulation*. Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Modeling_and_simulation

Woodin, T., Feser, J., & Herrera, J. (2012). The vision is set, now help chronicle the change. *CBE Life Sciences Education*, *11*(4), 347–350. https://doi.org/10.1187/cbe.12-09-0162

Woolfork, A. (2017). *Educational Psychology* (13th Edition). Pearson.

Wyzant. (2021). *Behind the Screen; Wyzant Online Learning Report 2021.* Wyzant News.

https://www.wyzant.com/blog/one-year-into-the-pandemic-wyzant-survey-of-tutors-reveals-rise-in-learning-loss-and-pandemics-impact-on-online-learning/

Appendix A

Competencies, Solicitation Emails, and Interview Questions

Table A1. Vision and Change Key Concepts and Core Competencies

- *Key concepts* that students must understand in order to become biologically literate.
    - 1) evolution (the diversity of life-forms that have evolved through mutations, selection, and genetic change;
    - 2) structure and function (the basic units of biological structures that define the functions of all living things);
    - 3) information flow, exchange, and storage (the influence of genetics on the control of the growth and behavior of organisms);
    - 4) pathways and transformations of energy and matter (the ways in which chemical transformation pathways and the laws of thermodynamics govern the growth and change of biological systems); and
    - 5) systems (the ways in which living things are interconnected and interact with one another).

- *Core competencies* that students must experience in order to become biologically literate and practice science.
    - 1) the ability to apply the process of science;
    - 2) the ability to use quantitative reasoning;
    - 3) the ability to use modeling and simulation;
    - 4) the ability to tap into the interdisciplinary nature of science;
    - 5) the ability to communicate and collaborate with other disciplines; and
    - 6) the ability to understand relationships between science and society.

Table A2. Volunteer Solicitation Email

Hello Bio 1010 Scientist, Your help is needed. Would you please assist me with a research project for the Otterbein Education Department? It is very low effort on your part, and your input would be appreciated greatly. I have a quick set of interview questions I need to ask you as you close out your semester in the online Biology 1010 course. I predict a quick, painless, and fun experience. Your identity will be confidential and answers will be used for a graduate research study looking at student experiences when labs are online. You can see how beneficial your viewpoint would be. Your answers, and viewpoint, are so uniquely yours as to be irreplaceable. Please reply back, and I will send you a zoom meeting link and set up a time. Thank you so much!

Table A3. Statistics Analyzing Chi-Squared Goodness-of-Fit of the Interviewees as Representative of the Class as a Whole

Class as a whole					Interviewees						
Gender		%			Gender	Expected	Difference Seen-Expected	(Diff^2)	Diff^2/Exp		
Male=	40	0.289855072		Male=	2	3.47826087	-1.47826087	2.19	0.62826087	α=.05	
Female=	98	0.710144928		Female=	10	8.52173913	1.47826087	2.19	0.256433008	df=1	
							Chi-Square Gender		0.884693878	Reject H0 if greater than 3.84	
Ethnicity				Ethnicity							
Caucasian/White=	107	0.775362319		Caucasian/White=	7	9.304347826	-2.304347826	5.31	0.570702966		
Asian=	4	0.028985507		Asian=	2	0.347826087	1.652173913	2.73	7.847826087		
Hispanic=	7	0.050724638		Hispanic=	1	0.608695652	0.391304348	0.15	0.251552795		
Two or more=	10	0.072463768		Two or more=	2	0.869565217	1.130434783	1.28	1.469565217	α=.05	
Black/African American=	10	0.072463768		Black/African American=	0	0.869565217	-0.869565217	0.76	0.869565217	df=4	
							Chi-Square Ethnicity		11.00921228	Reject H0 if greater than 9.49	
Grades				Grades							
A	79	0.572463768		A	4	6.869565217	-2.869565217	8.23	1.198679141		
B	35	0.253623188		B	6	3.043478261	2.956521739	8.74	2.872049689		
C	11	0.079710145		C	1	0.956521739	0.043478261	0.00	0.001976285		
D	6	0.043478261		D	1	0.52173913	0.47826087	0.23	0.438405797	α=.05	
F	7	0.050724638		F	0	0.608695652	-0.608695652	0.37	0.608695652	df=4	
Total	138			Total	12		Chi-Squared Grades		5.119806565	Reject H0 if greater than 11.07	
H0=Interviewees are representative of the class as a whole											
Ha=Interviewees are not a perfect representation of the class as a whole											
For Gender, Interviewees are representative											
For Ethnicity, Interviewees are not representative											
For Grades in the course, Interviewees are representative											

Appendix B

Examples of Interview Transcripts, Frankie, Pat, Jamie

Transcript B1. Frankie

Interviewee Pseudonym: Frankie
December 8, 2020
Wifi problems. Used Collaborate Ultra's Chat Feature
Did not attend a second interview

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?

No, I don't really remember

2. Can you tell me about times when the online laboratory format gave you practice in formulating hypotheses?

Yeah-In the DNA lab, we had to have hypothesis of what we think was happening.

3. Can you tell me about times when the online laboratory format gave you practice in testing hypotheses experimentally or observationally?

Let me think. I don't really remember exactly. Sorry.

4. Can you tell me about times when the online laboratory format gave you practice in analyzing experimental or observational results?

Yeah, when we had the gel lab, we had to look at the results & analyze it.

5. Can you tell me about times when the online laboratory format gave you an exposure to quantitative reasoning?

Yeah, the last lab we had about the human species.

6. Can you tell me about times when the online laboratory format gave you an exposure to Modeling and simulation?

I can't think of one.

7. Can you tell me about times when the online laboratory format gave you an exposure to the interdisciplinary nature of science?

We had a lab about viruses. Would that work?

8. Can you tell me about times when the online laboratory format gave you an exposure to Communication and collaboration?

I mean the only time we collaborate with other students was when we were going over our hypothesis and see who has the same thinking.

9. Can you tell me about times when the online laboratory format gave you an exposure to the relationship between science and society?

Can't really think of one.

Transcript B2. Pat

Interviewee Pseudonym: Pat
January 5, 2021
Audio problems. Used Collaborate Ultra's Chat Feature
Did not attend a second interview

Pat: Good afternoon! Yes I can hear--Should I switch to my phone because my computer mic is broken

Researcher: I can't hear you, but can hear me. We can this via chat, if you'd like. That works, too.

Pat: one moment!

Researcher:

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?

Pat: I'm on. Yes.

Researcher:

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?

Pat: There was a procedure to every single lab we had and we never had a lab without reviewing the chart

-

Researcher:

2. Can you tell me about times when the online laboratory format gave you practice in formulating hypotheses?

Pat: .. not that I can remember sorry

Researcher:

3. Can you tell me about times when the online laboratory format gave you practice in testing hypotheses experimentally or observationally?

Pat: Yes, the strawberry DNA extraction let me learn something new and formulate and test hypotheses with my classmates that everything MAY have DNA in it

Researcher:

4. Can you tell me about times when the online laboratory format gave you practice in analyzing experimental or observational results?

Pat: The yeast lab where observations were key to figuring out the correct results

Researcher:

5. Can you tell me about times when the online laboratory format gave you an exposure to quantitative reasoning?

Pat: The Yeast Lab and Fermentation

Researcher:

6. Can you tell me about times when the online laboratory format gave you an exposure to Modeling and simulation?

Pat: The COVID Lab had more modeling and simulation and we had to use that to determine diseases

Researcher:

7. Can you tell me about times when the online laboratory format gave you an exposure to the interdisciplinary nature of science?

Pat: The final lab on Genetics and the study of various races

Researcher:

8. Can you tell me about times when the online laboratory format gave you an exposure to Communication and collaboration?

Pat: Breakout rooms where we solved problems and answered questions together (in the first half of the semester)

Researcher:

9. Can you tell me about times when the online laboratory format gave you an exposure to the relationship between science and society?

Pat: The lab with study of genetics and the study of diseases and how various people inherit various types of diseases

Thank you much!
Have a blessed day you too

Researcher: Bye! Thank you!

Transcript B3. Jamie

Interviewee Pseudonym: Jamie
December 17, 2020
Audio problems. Used Collaborate Ultra's Chat Feature
Attended a second interview which merited a second transcription

•

Jamie:

6:02 PM
i have my microphone on yes!

Jamie: im talking but it isnt picking up!

Researcher: Check that the computer itself isn't muted

Jamie: that sounds good!

Researcher:

1. Can you tell me about times when the online laboratory format gave you an exposure to the scientific method?

Jamie: Definitely the yeast labs made me think of and try to use the scientific method.

Researcher:

2. Can you tell me about times when the online laboratory format gave you practice in formulating hypotheses?

Jamie: Again, I would say the yeast labs. I would also say the genome lab, as wel.

Researcher:

3. Can you tell me about times when the online laboratory format gave you practice in testing hypotheses experimentally or observationally?

Jamie: I would say the biggest one was one of the last labs we did: The chromosome lab

Researcher:

4. Can you tell me about times when the online laboratory format gave you practice in analyzing experimental or observational results?

Jamie: Definitely the chromosome lab. We had to do that one mostly on our own, so it was very thought provoking. Since the yeast lab was in 3 parts, I believe, that had a lot of analytical thought had to go into answResearcherg the questions via observation and answer independently and honestly.

Researcher:

5. Can you tell me about a time when the online laboratory format gave you an exposure to quantitative reasoning?

Jamie: The yeast lab had a lot to do with counting how many yeast colonies were present, so that one in particular stuck out to me the most.

Thank you!

Researcher:

6. Can you tell me about times when the online laboratory format gave you and exposure to Modeling and Simulation?

Jamie:

Definitely the Fermentation Lab with videos about Fermentation, and the Human Genomes one where we had to use two different websites to: find certain genes/what that particular sequence on the gene (that we were finding) job or function was, and what population or race it affected (ancestral or present wise)

Researcher:

7. Can you tell me about times when the online laboratory format gave you an exposure to the interdisciplinary nature of science?

Jamie: The COVID lab did give us pupils insight to not only the scientific side of the virus but also the intellectual side of the virus (like how important is it to properly diagnose one with a disease and or virus, or any sort of thing wrong in the body). The Human Genome Lab gave us racial insight from a genome and humane perspective, but me personally I like to look at labs biologically rather than liberally.

Also I adore your cat.
Sounds like my cat, [omitted]

Researcher:

8. Can you tell me about times when the online laboratory format gave you an exposure to Communication and Collaboration?

Jamie: We didn't really "collaborate" with other students. It was mostly us pupils watching videos of them doing the lab and just copying answers they said to us. To me, it was a very ineffective way to learn and absorb

information. I didn't retain any important information, but rather just gave the correct answers that I consciously absorbed for a short parameter of time that the Professor fed me.

I'm a very visual learner, so that's how I learn best.

Researcher:

9.Can you tell me about times when the online laboratory format gave you an exposure to the relationship between science and society?

Jamie: Without it there's a disconnect.

I see science in everything I do. They did drive home the relationship between science and the outside society. Science is webbed into very aspect of life. Even so, science and people's perception of it changes their outlook on society. How each of us learn science, which can be influenced by background and how you've grown to think the world and everything in it functions, can alter how you view society. How you view science usually alters or influences how you see society.

Sounds good. Do you have any other cats?

That's adorable. Sounds like my other cat, [omitted]. But she's still here being picked on by [omitted]

Of course! It was wonderful talking to you!!

You too!

Appendix C

Course Laboratory Schedules, In-person and Online

Table C1 In-person Laboratory Schedule Example from Autumn 2019

Week	Laboratory Topic	Laboratory Activity
1	Lab Safety/Scientific Method	(Exercise 1) Yeast Respiration
2	Measurements in Biology	(Exercise 2) Mass, Distance, Volume
3	Microscopy & Ecology	Microscopy + Alum Creek (Exercise 3)
4	The Cell	(Exercise 4) Protists, and cell types
5	Membranes	(Exercise 9) Diffusion and Osmosis
6	Cellular Replication	(Exercises 14 & 15) Meiosis and Mitosis
7	Heritability and DNA	(Exercise 17) Principles of Mendel and DNA models
8		NO LAB
9	Anthropology and Evolution	Common Book Week H. naledi Exercise
10	Genetic Manipulation	(Exercise 16) DNA Isolation and Transformation
11	Population Genetics	Hardy-Weinberg mating assortment
12	Conservation	Elephant Selection and Poaching
13	Carrying Capacities and Growth Curves	(Exercise 22) Population Growth and Environment
14		NO LAB
15	Anthropology and Human Evolution	(handout + Exercise 19) Human Evolution: Skull Examination

Table C2 Online Laboratory Schedule Example from Autumn 2020

Week	Laboratory Topic	Laboratory Activity
1	Introduction Laboratory Safety, Scientific Method, Scientific Publications	Virtual Lab Tour, Finding an Academic Paper
2	Heritable Material	Strawberry DNA Extraction
3	Central Dogma	Biobits Central Dogma Lab
4	No Lab	
5	Reproduction and Cell Division	Mitosis of Onion Root Tip Cells
6	Evolution Applied	Yeast Mutagenesis Week 1
7	Evolution Applied	Yeast Mutagenesis Week 2
8	Evolution Applied	Yeast Mutagenesis Week 3
9	Molecular/Cell Structure and Function	Viral Diagnostics Gel Kit, COVID-19 Videos, and Exercise
10	Photosynthesis	Chlorophyll Chromatography
11	Cellular Respiration	Fermentation
12	No Lab	
13	Evolution of Eukaryotes	The Human Genomes Project
14	No Lab	
15	No Lab	

Signature Attachment

From: Cho, Daniel
Sent: Friday, April 30, 2021 1:42 PM
To: Ulrich, Erin <
Subject: Re: Signature, please?

Hi Erin,
I do not have an electronic signature, but if you use this email, it should act as my signature.

Get Outlook for iOS

From: Ulrich, Erin <
Sent: Friday, April 30, 2021 1:40:16 PM
To: Cho, Daniel <
Subject: Signature, please?

Hi Dr. Cho,
When you get a chance, can I get you to sign the first page of this document? …
Thank you very much for all your help. …
Best to you,
Erin