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An Analysis of Undergraduate Microbiology Students' Beliefs and Attitudes Related to Virtual Learning

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Abstract

Since the inception of the Coronavirus disease (COVID-19) pandemic, undergraduate microbiology students globally have had their education disrupted causing uncertainty with their education, learning, and career trajectories. Undergraduate students have faced challenges with the transition of online/virtual learning and interacting with their fellow colleagues and instructors. The COVID-19 pandemic challenged the education system globally and created a major paradigm shift that forced educators of all levels to adjust their traditional face-to-face pedagogy to an online mode of pedagogy instantaneously. I initiated this study because of the dilemma that the COVID-19 pandemic had on students' experiences and instructors' in meeting the challenges of transferring a course entirely online in a relatively very short time. The purpose of this study is to investigate the following: (1) to what extent do undergraduate students change their knowledge about topics in microbiology relevant to the course presented online? (2) to what extent do the undergraduate students change their opinions relating to topics addressed in a microbiology course relevant to the course presented online? (3) how do undergraduate students experience computer-based learning in a microbiology course relevant to the course presented online?

Keywords: Face-to-face learning, microbiology, online learning, pedagogy, undergraduate students

Introduction

The transition from formal face-to-face learning to virtual learning is challenging for all undergraduate students, especially those who aspire to major in the field of biological sciences (Seitz, 2021). The coronavirus disease (COVID-19) pandemic has introduced educators and curriculum developers to novel methods of addressing education for undergraduate microbiology students (Lischer et al., 2021).

In some cases, traditional face-to-face lectures have been adapted rapidly to be delivered virtually and/or asynchronously online using various educational platforms or learning management systems such as Canvas, Blackboard, Cisco Webex, and Zoom. Because these educational platforms already exist in most educating institutions, colleges and universities worldwide have accelerated the development and implementation of an online learning environment. For example, K-12 schools, colleges/universities, educators, and students have increasingly adopted computer-based learning, e-learning, and other educational technologies that encourage educators to transmit and transform their pedagogy interactively, share resources via. internet, and facilitate student learning, collaboration and engagement (Kozlowski, 2002).

Given these challenges and substantial changes that have been taking place during the COVID-19 pandemic, the purpose this research is to explore undergraduate students' perceptions of, and attitudes about, acquiring content knowledge and skills in microbiology and biology, while being taught online, and how often they participate in online courses compared to face-to-face courses. Moreover, this work is also intended to elucidate which mode of learning (offline or online) they would prefer.

Online versus face-to-face education

The COVID-19 pandemic has been a portentous event throughout the world, especially for undergraduates who were challenged by the rapid transition to a very different learning mode that in many cases seems to have exceeded their capacity to acclimate to the new online/virtual education (Lischer et al., 2021; Kozlowski, 2022; Szopiński and Bachnik, 2022).

Online learning is a form of distance education which mainly involves the learner to have a computer and/or tablet and to have access to the internet. Courses are offered virtually/synchronously (i.e., live online) such as video conferences and virtual classrooms and/or asynchronously (i.e., recorded videos and podcasts) in which students access course materials online, provided by the instructor, and they are given a timeline to complete it at their own pace (Olivet et al., 2016). Many authors describe online learning as access to learning experiences involving internet-based education and other technological devices (PDFs, audio files, and videos) for synchronous and asynchronous instructional delivery of educational content (Biel and Brame, 2016; Zheng et al., 2021; Szopiński and Bachnik, 2022; Joshi, 2021). In online education, instructors design learning environments, as well as experiences, that are accessible to their students, while facilitating and overseeing student progression.

In terms of academics, prior to, and during the COVID-19 pandemic, the majority of undergraduate used the internet to acquire some form of content knowledge. Online learning was, widely implemented to benefit undergraduate's learning. However, some undergraduate courses such as anatomy and physiology may perhaps be more engaging and conceptual face-to-face as opposed to learning online/virtually (Franchi. 2020). Many researchers support traditional face-to-face pedagogy stating that it is more beneficial for undergraduates because of the way traditional classes are organized, it provides consistent facilitation with students' learning progression and can help them better understand difficult concepts that may be esoteric (Kemp & Grieve, 2014; Zhao & Watterston, 2021). Some researchers have indicated the level of comprehension has significantly decreased during online learning; and, in some cases, students have developed idiosyncrasies associated with their academics including anxiety, stress, and procrastination (Lischer et al., 2021; Melgaard et al., 2022).

Challenges of undergraduate online learning

Although these educational platforms can provide an effective interactive learning experience for undergraduates, an increasing body of evidence has indicated mixed results for undergraduate biology majors (Biel and Brame, 2016). For example, Zheng, Bender, and Lyon (2021) surveyed 482 predoctoral students in a U.S. dental school regarding their preferences for face-to-face instruction versus online instruction. Fifty percent of the students preferred face-to-face instruction, while the other half preferred online. Pei and Wu (2019) reviewed articles and reported on the effectiveness of online learning versus offline learning for medical undergraduate students in Beijing, China including "comparing post-test scores, pre- and post-test score gains and retention test scores" (p. 5). They concluded that online learning is equally as effective as offline learning. Nonetheless, there are many variables to take into consideration including: learning goals, age of the participants, and duration of the course. Sarvary, Castelli,

and Asgari, (2022) conducted research with 350 undergraduates using online modules in microbiology and in ecology with an emphasis on laboratory skills. Eighty-two percent of the undergraduates preferred face-to-face laboratory assignments as opposed to online; 53% preferred face-to-face presentations as opposed to online. However, over 60% of undergraduates favored submitting assignments, lectures, exams, and asking questions online as opposed to face-to-face.

Professional development challenges and curriculum development

One likely explanation for these varied experiences was due to the lack of prior undergraduate engagement with computer-based learning as well as passive-teaching and learning that, especially during the COVID-19 pandemic (Lischer et al., 2021), has been very common in undergraduate biology courses. Both undergraduates and faculty had to acquire new pedagogical and technology-based skills and strategies, promptly. After several months from March of 2020 to December 2020 (totaling nearly two years as of 2022), teaching and learning has been largely in this new highly virtual mode. Moreover, many professors lack the professional development needed to implement biological content knowledge online and/or virtually (Brownell & Tanner, 2012; Hancher-Rauch et al., 2021; Rowland et al., 2022) and because of this, undergraduates who are generally more accustomed to formal/face-to-face pedagogy and learning are now faced with a myriad of adverse academic transitions. This includes, but is not limited to, curriculum revisions (Crumb et al., 2020), acclimation with technology-based resources and educational platforms (Saher & Anjum, 2021) student evaluation and assessment (Szopiński & Bachnik, 2022) and changes in the ways examinations (midterm and final) are administered. Given these uncertainties, colleges and universities have endeavored to transform their educational format to full online learning until face-to-face instruction is once again feasible, assuming they choose to do so.

Addressing undergraduate students' challenges with these new learning paradigms

With these educational and learning paradigm shifts, it is important to measure undergraduates' experiences and perceptions with learning the biological sciences, particularly microbiology. Among other reasons, including ethical and professional responsibilities, there is a pressing need to ensure that undergraduates are motivated, confident, and satisfied with learning virtually and using computer-based learning in lieu of face-to-face pedagogy. Additionally, these paradigm shifts require consistent preparation, advanced planning, and training for educators to make the students' experience conducive to learning (Szopiński & Bachnik, 2022).

This research study addresses these topics, as well as exploring undergraduate students' perceptions of, and attitudes about, acquiring content knowledge and skills in biology and microbiology while being taught online.

Numerous studies have been conducted on various facets of the impact COVID-19 had on teaching biology courses at the undergraduate level (Seitz, 2021; Sánchez-Angulo, et al., 2021; Joshi, 2021). This research was conducted among biology and STEM major undergraduates attending an urban college in New York City, U.S.A.

The remainder of this paper is organized as follows: The first section lists the research questions of this study. The second section identifies the materials and methods, which includes the microbiology course, participants, data gathering and instruments, rationale for the design of the questionnaire, rationale for the design of the Likert scales, rationale for the survey, and statistical methods. The third section analyzes the results of the research. The final section presents the discussion of the research, the research limitations, and the conclusion.

Research questions

Each of the following research questions addresses one of the three purposes stated previously.

Research Question 1. To what extent do undergraduate students change their knowledge and opinions about topics in microbiology relevant to the course presented online?

Research Question 2. To what extent do the undergraduate students change their opinions relating to topics addressed in a microbiology course presented online?

Research Question 3. How do undergraduate students perceive their experiences when using a computer-based interactive learning approach in a microbiology online course?

The purpose of this research was to analyze and evaluate undergraduate students' perceptions of, and opinions about, their experiences of online learning in a microbiology course. The results are discussed and suggestions presented to more effectively support online/virtual learning in the field of microbiology and biology education, specifically, since more students now (2020-present) use computers, the internet, and online resources for learning.

Materials and Methods

Study design

This research was an analytical study designed to assess and evaluate undergraduate students' perceptions of the learning experience quality of an online microbiology course. The following dimensions were assessed: *Awareness of microbiology, human diseases and related topics; Human health and diseases, the use of hand sanitizers, vaccines, and antibiotics; Bacteria, viruses, and human diseases; Prior knowledge of bacteria, viruses, and human diseases;* and *Attitudes and beliefs towards virtual learning and computer-based learning*.

The Likert scale was adapted from Sancho et al. (2006), Masiello, Ramberg, and Lonka (2005), and Carver et al. (2017); and an online Sign Test Calculator was used for statistical analysis (as explained more fully below).

Description of the virtual microbiology course

The microbiology course was developed and designed to be a welcoming experience for undergraduate biology majors in an urban college setting. Undergraduates were introduced to microbiology concepts as well as interdisciplinary science skills and strategies that were particularly relevant to their respective fields of study (forensics, physician assistant, molecular biology, toxicology, etc.). The microbiology course content was organized and delivered utilizing the *Blackboard* learning management system. Instruction was delivered using the following pedagogical practices to accommodate virtual learning: computer-based learning, student-centered learning, lecturing, and adopting a learning community.

During the first session of the course (Day 1) undergraduate students were asked if they would volunteer to take a Likert scale pre-survey to document their opinions of their *Attitudes and Beliefs Towards Microbiology and Attitudes and Beliefs Towards Computer-Based Learning*. The same five-point voluntary Likert scale was administered on the last day of the course to the undergraduate students who agreed to take it, as a way of documenting and interpreting any shifts in their responses, after taking the course.

At the beginning of the week, the instructor assigned a reading article taken from journals in the fields of science, biology, virology, and microbiology. Undergraduate students wrote a reflection assignment about these articles based on the article's genre. These genres included:

- Association to their major (toxicology, biology, etc.)
- Relationship to their career
- Related to modern issues in science and/or STEM
- Increase their level of content knowledge
- Connect to their personal lives

Before each virtual class, the course instructor encouraged undergraduates to volunteer their reflections of the assignment by gathering their responses to the assigned article, reflective thoughts, opinions, etc. This allowed the instructor to gauge the following: (1) undergraduate's prior content knowledge relevant to the required learning material for the upcoming class, (2) student's perception, attitudes/opinions of the course material, as well as what was challenging for them to understand, and (3) developing their interdisciplinary skills. This set the pathway to discuss the lecture, acquire students prior content knowledge, implement a computer-based learning assignment, address and dispel common misconceptions, and foster student-centered learning.

Grading in the course was based on two exams (a midterm and final), weekly reflections, individual presentation, and class participation during class discussions and responses to the instructor's queries during the lecture. The microbiology course lessons were grouped into seven (7) units:

- Microbiology Fundamentals and Epidemiology
- Microbial Growth and Culturing Bacteria
- Pathogenic Microbes
- Control of Microorganisms
- Host-Microbes Interactions
- Infectious Diseases of the Systems of the Human Body
- Deadly Diseases
- Environmental and Applied Microbiology

During the development of this course, 28 traditional lectures that had been delivered in 90-minute class periods were taught virtually (Table 1).

Table 1: Week-by-week lecture topics taught virtually.

Week	Virtual lecture	Reflection article	Computer-based learning (CBL)
1	Course introduction, scope of microbiology and careers	*The real domains of life*: Walsh and Doolittle, (2005)	https://www.biointeractive.org/classroom-resources/bacterial-identification-virtual-lab
2	Introduction to the Center for Disease Control and Prevention	*The Education of Physicians: A CDC Perspective*: Koo and Thacker (2008).	https://www.cdc.gov/health-topics.html
3	Introduction to epidemiology and its association to microbiology	*Bacterial Morphology: Why have different shapes?* Young (2007)	https://www.cdc.gov/nors/about/index.html https://www.cdc.gov/nors/data/index.html https://wonder.cdc.gov/
4	Characteristics of bacterial cells	*The evolution of bacterial social life: From the ivory tower to the front lines of public health*: Pepper, (2014).	https://bergeys.org/publications https://learn.genetics.utah.edu/content/microbiome/intro/#bacteria https://learn.genetics.utah.edu/content/cells/scale/
5	Microbial growth	*What's the best bacterial shape?* Hofer, (2019).	https://biocascades.com/articles/identifying-bacteria-in-petri-dishes/ https://microbiologysociety.org/why-microbiology-matters/what-is-/
6	Introduction to Viruses	*Viruses and the Microbiota*: Robinson and Pfeiffer (2014)	https://media.hhmi.org/biointeractive/click/virus-explorer/
7	Microorganisms, diseases, and transmission	*What is a disease?* Scully (2004).	https://www.cdc.gov/digital-social-media-tools/mobile/applications/sto/web-app.html
8	Emerging and re-emerging infectious diseases	*Emerging and Re-emerging Infectious Diseases*: Löscher and Prüfer-Krämer (2010).	https://www.cdc.gov/vector-borne-diseases/ https://www.cdc.gov/ncezid/ https://www.cdc.gov/climate-health/php/effects/vectors.html
9	General properties of antimicrobial agents	*The Future of Antibiotics and Resistance*: Spellberg, Bartlett	https://amr.longitudeprize.org/superbugs-game/

		and Gilbert, (2013).	
10	**Midterm**		
11	Diseases of the integumentary system: Skin, eyes, wounds	*Integumentary System*: Mauldin, and Peters-Kennedy, (2016).	https://www.learnderm.com/
12	Diseases of the respiratory system	*Viral and bacterial interactions in the upper respiratory tract*: Bosch et al., (2013).	https://meetingarchive.ami.org/2020/project/cellaritys-anthem-what-ifild-diagnosis-detective/
13	Diseases of the nervous system	*Infectious Diseases of the Nervous System and Their Impact in Developing Countries*: Bruzzone, Dubois-Dalcq, Grau, Griffin, and Kristensson, (2009).	https://www.mededportal.org/doi/10.15766/mep_2374-8265.9617
14	Diseases of the cardiovascular system	*Persistent viral infections and their role in heart disease*: Badrinath, Bhatta & Kloc, (2022).	https://www.biointeractive.org/classroom-resources/cardiology-virtual-lab
15	Diseases of the digestive system	*Infections of the Gastrointestinal Tract*: Lauwers, Mino-Kenudson & Kradin, (2010).	https://microbe.net/gutcheck/
16	Diseases of the Gastrointestinal system caused by protozoan and helminth	*Human intestinal parasites*: Haque, (2007).	https://www.educaplay.com/learning-resources/6970141-helminths.html
17	Urogenital and sexually transmitted diseases	*Sexually Transmitted Diseases*: An Overview. Lytle-Barnaby (2016).	https://stdwizard.com/#/home
18	Ectoparasites that cause human disease	*Who Bites Me? A Tentative Discriminative Key to Diagnose Hematophagous Ectoparasites Biting Using Clinical Manifestations*: Akhoundi et al., (2020).	https://www.cdc.gov/digital-social-media-tools/mobile/applications/sto/web-app.html
19	**Comprehensive Final Examination**		

Based on the educational objectives, each unit was implemented within a different learning module. Some of the learning techniques that made the course more welcoming were utilizing student-centered and collaborative learning approaches within the context of a virtually taught course. A major goal was to enhance undergraduate students' capacity to acquire the content knowledge, as well as the academic skills, necessary for satisfactory completion of the course

by utilizing a variety of interactive websites that are microbiology, biology, and STEM-based.

Similar pedagogical approaches have been employed successfully in secondary and undergraduate education. For example, Southworth et al. (2010) recommended using a virtual laboratory environment to supplement, or substitute for, a traditional hands-on classroom laboratory. For more than twenty years "educational technology research has demonstrated the power of cyberlearning in helping students construct rich mental models of genetics" (Southworth et al., 2010; p. 3).

The research of Carver et al. (2017) used questionnaire-based evidence that examined undergraduate students' knowledge, beliefs, and attitudes pertaining to genetics and genomics and concluded that the student-centered approaches used in their study enhanced students' critical judgements about scientific decision making, especially as it may affect major societal and ethical dimensions.

Participants

This research was conducted at a public four-year college in New York City, New York, U.S.A. Among the 26 undergraduate students who enrolled in the course, 19 undergraduate biology majors agreed to be participants in the research study.

A questionnaire was used to acquire the participants' biographical information: age and gender, their level of college education, and level of prior knowledge in microbiology (none, high school level, college level). This questionnaire was used to better characterize the sample of students participating in this study (Pickering, 2017). Additionally, each respondent was asked the following question: What is your preferred learning format for learning microbiology content: Formally in a classroom setting, online/virtual learning or asynchronous learning?

The respondents who participated were assigned a number to maintain anonymity, and all information was stored in a secure laptop computer to prevent possible identification of the respondents and the location of where the research was done.

Data gathering instruments

Biographical questionnaire. Data was collected using a survey instrument that included a questionnaire on students' biographic and background information and four individual five-point Likert scale surveys each as explained more fully below. The undergraduate students' participation in the survey was completely voluntary, responses were anonymous and did not influence grading, and no personal information was collected. The data was collected on the first and last days of the course by email. University administrative approval was obtained to distribute the questionnaire and Likert surveys to the undergraduate students and utilize results for publication.

Rationale for the design of the questionnaire. A questionnaire provides an objective method of collecting information about people's content knowledge, opinions, beliefs and

attitudes (Paradis et al., 2016). The student questionnaire consisted of six questions, three of which focused on experience, exposure, and microbiology content. The remaining three questions gathered biographical information: age, gender, and the year that the participant began college. Questionnaires have the potential to provide evidence that can improve learning experiences and enhance student content knowledge and learning skills (Artino, La Rochelle, & Dezee et al., 2014) and are effective for improving student performance, providing the instructor offers a brief synopsis as to the validity of the questionnaire**.**

Likert scale survey instrument and development. A five-point Likert-scale survey was developed to examine undergraduate students' content knowledge and opinions and attitudes of the microbiology online virtual course. All of the undergraduate students were asked to complete the same pre-and-post five-point Likert-scale survey while reflecting on their prior experiences in biology online/virtual courses. The Likert survey consisted of 14 items (Tables 1-4) with one open-response choice.

Rationale for the design of the Likert scale survey. The Likert scale survey contained items to assess the undergraduate respondent's level of agreement or disagreement about statements that cover general feedback on the various aspects of the microbiology course. The items contained in the Likert scales are listed in the Results (Tables 1-4) including pertinent findings for each item.

Likert scale surveys are an easy and convenient method to measure and evaluate opinions, attitudes, beliefs, and other characteristics (Sullivan & Artino, 2013) in academic setting and in fields of socio-cultural research. Jebb, Ng, and Tay, (2019) describe the frequent use of a Likert scale survey as "a convenient way to measure unobservable constructs, and published tutorials detailing the process of their development" (p.1). Likert scales are very useful in education, medical education and general education research, particularly when researchers are attempting to measure topics that are opinionated.

For this research, four dimensions were assessed using a five-point Likert scale format with the following response options: *Completely Disagree, Disagree, Neutral, Agree, Completely agree*. Likert scales 1–3 addressed three of the four dimensions: (1) student knowledge, (2) opinions and attitudes pertaining to microbiology; and (3) and awareness of microbiology concepts. Likert scale 4 addressed the 4th dimension (4) virtual learning and computer-based learning. Factors that may influence student attitudes towards online learning include the level of proficiency and comfort with online learning, easy access to log-on and join the class, their commitment to learning, student professor interaction, and technical aptitude (Zheng et., 2021; Szopiński & Bachnik, 2022).

Given the challenges that undergraduate students currently have, and likely will have in the future, related to online learning, particularly in microbiology; the rationale for this study was to assess and more fully analyze undergraduate students' understanding and their perceptions of learning microbiology. Some of the items in the Likert scale specifically addressed opinions and other items were designed to address undergraduate students' understanding of major principles of microbiology, virology, and human health. The latter particularly were used to assess student's content knowledge in the field.

A five-point Likert-item response format was used, as opposed to a four-point, forced response format, because a forced response format has no neutral option, which does not fully represent a respondent's status who genuinely has a neutral orientation to the content of the item. Moreover, a five-point response format provides more comprehensive evidence to document possible changes in the respondent's response to the items, particularly the capacity to detect a change from neutral to one of the other polar options in the Likert scale item.

Statistical Methods

Descriptive statistics was used to report the biographical evidence collected with the questionnaire. Additionally, descriptive statistics was used to analyze the results of the Likert surveys including frequency of responses to each item and the equivalent percentages of the responses on each of the Likert scale items using a Microsoft Excel Spread Sheet. The frequency of responses to each option of a Likert scale item was converted to a numerical score where the values were as follows: *Completely Disagree (1), Disagree (2), Neutral (3), Agree (4), and Completely Agree (5).* In the Results (Tables 1–4), data for the Likert scale items is reported as the percentage of respondents choosing each option followed by the frequency of respondents who chose the option enclosed in parentheses. The final entry in each row of a results table is the mean Likert numerical score for the item.

An online Sign Test Calculator (https://www.socscistatistics.com/tests/signtest/default.aspx) was used to determine the statistical significance of the mean difference between the pre- and post-survey means for each Likert scale item, because the data were not normally distributed, and a non-parametric test was required. The significance level was set at $p \leq 0.05$.

Results

Each research question and the related results will be addressed sequentially.

Research Question 1

The results of the initial and final Likert surveys, addressing Research question one on *Attitudes and Beliefs Towards Microbiology* are presented in Tables 1 and 2. The results in Table 1 addressed respondents' opinions regarding the Likert dimension of *Awareness of microbiology, human diseases and related topics* and Table 2 addressed respondents' opinions (Items 1, 2, and 5) and knowledge (Items 3 and 4). These two items address knowledge, because they deal with accuracy of students' understanding related to applications in microbiology and human health.

Of the four items in Table 1, there were three items (Items 1, 3, and 4) that had statistically significant results. Item 1 involved learning about human diseases; with a mean Likert score of 4.58 on the pre-survey, with most of the respondent's selecting Agree (A) or Completely Agree (CA). The post-survey mean Likert score was 4.89 indicating a shift largely toward the Completely Agree (CA) range ($p < 0.05$). Item three dealt with aspects of microbiology and the ethical, legal, and social implications for human societies. The mean Likert score on the

pre-survey was 4.37, with most of the respondent's selecting Agree (A). The post-survey mean Likert score was 4.84 indicating a shift toward the Completely Agree (CA) range ($p < 0.01$). Item four was associated with the perceptions that learning microbiology will enhance their preparation for a career in the field of STEM and/or medicine. The mean Likert score on the pre-survey was 4.53 with most of the respondent's selecting Agree (A) or Completely Agree (CA). The post-survey mean Likert score was 4.11 indicating a shift toward Neutral (N) and Completely Agree (CA) ($p < 0.01$). The results for Item two was not statistically significant.

Table 1 Comparison of pre- and post-survey Likert scale responses to items in Section 1 for the dimension: *Awareness of microbiology, human diseases and related topics.*

Item 1. I believe it is important for students like me to learn about human diseases. *

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	5 (1)	32 (6)	63 (12)	4.58
Post-survey	0	0	0	11 (2)	89 (17)	4.89

Item 2. In my opinion, I think learning microbiology will improve my understanding of other courses such as genetics, human health, and STEM. ***ns***

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	0	32 (6)	68 (13)	4.68
Post-survey	0	0	5 (1)	5 (1)	89 (17)	4.84

Item 3. It is important to study microbiology, because these ideas are increasingly important in ethical, legal, and social aspects of human societies. **

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	0	63 (12)	37 (7)	4.37
Post-survey	0	0	0	16 (3)	84 (16)	4.84

Item 4. I believe that learning the factual concepts and processes of microbiology will improve my learning in college and better prepare me for a career in the field of STEM and/or medicine. **

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	11 (2)	26 (5)	63 (12)	4.53
Post-survey	0	0	32 (6)	26 (5)	42 (8)	4.11

Data are presented as percentages and as frequencies in parentheses. Abbreviations of response options are defined as follows: *CD: Completely Disagree; D: Disagree; N: Neutral; A: Agree; CA: Completely Agree*. Statistical significance is indicated as follows: *ns non-significant, * significant ($p \leq 0.05$), **($p \leq 0.01$)*. This format is consistently used for all of the succeeding tables.

In general, the responses were highly favorable for both the initial and final administration of the Likert survey for the data addressing Research question one (Table 1). With reference to Dimension 1: *Attitudes and Beliefs Towards Microbiology*; most of the respondents selected Agree (A) or Completely Agree (CA) on the four items. Most notably, for Items 1, 2, and 4, the percentage of 'A' and 'CA' positive responses compositely exceeded 90% for both the initial and final surveys. For Item 4, there was a shift downward toward Neutral (N) by four students in the final administration of the survey. Initially, two students responded by choosing 'N,' but in the final administration six students chose the neutral option.

Overall, students' attitudes, beliefs, and interests towards a virtual undergraduate microbiology course was positive, particularly since this was an elective course and the majority of students had a background/undergraduate major in science. Apart from Items 3 and 4, the responses were less favorable for both the initial and final administration of the Likert survey (Table 1) addressing Question One, with reference to Dimension 1: *Awareness of microbiology, human diseases and related topics.*

Dimension 2 of Research question one (Table 2) has five (5) Items associated with several different themes as follows. Items 1 and 2 address human health policies. Items 3 and 5 particularly addressed significant knowledge that modern citizens should have to be better prepared in addressing important policy issues related to the content in Items 1 and 2. In order to better assess students' ability to make discriminative decisions, Item 4 was designed to determine if they can detect an incorrect statement that would be relevant to policy decisions; namely, to recognize that antibiotics are not used for viral infections.

Table 2 Comparison of pre- and post-survey Likert scale responses to items in Section 2 for the dimension: *Human health and diseases, the use of hand sanitizers, vaccines, and antibiotics.*

Item 1. Regardless of the type of disease, if a person has a contagious disease that causes illness, is it acceptable to require that they undergo a mandatory treatment to try to treat and/or cure this disease so they will not infect others. **ns**

	CD	D	N	A	CA	Mean Score
Pre-survey	11 (2)	0	5 (1)	47 (9)	37 (7)	4.00
Post-survey	0	0	32 (6)	26 (5)	42 (8)	4.11

Item 2. Some vaccines can prevent the spread of deadly human diseases. In your opinion, should government agencies make it mandatory for vaccines to be administered ONLY for deadly human diseases? **ns**

	CD	D	N	A	CA	Mean Score
Pre-survey	0	26 (5)	26 (5)	42 (8)	5 (1)	3.26
Post-survey	21 (4)	11 (2)	37 (7)	11 (2)	21 (4)	3.00

Item 3. Hand sanitizers and disinfectants should be used on our hand and surfaces on a daily basis. *****

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	16 (3)	42 (8)	42 (8)	4.26
Post-survey	42 (8)	21 (4)	11 (2)	16 (3)	11 (2)	2.32

Item 4. Antibiotics are useful for viral infections. ******

	CD	D	N	A	CA	Mean Score
Pre-survey	26 (5)	16 (3)	11 (2)	42 (8)	5 (1)	2.84
Post-survey	68 (13)	11 (2)	11 (2)	11 (2)	0	1.63

Item 5. Modern scientific research has discovered that certain bacterial organisms improve human health, and thus, studying these bacterial organisms may help us to better understand the symbiotic relationship between bacteria and human health. However, this is expensive research. In your opinion should our government use taxes to help support this kind of research? **non-significant**

	CD	D	N	A	CA	Mean Score
Pre-survey	5 (1)	0	16 (3)	42 (8)	37 (7)	4.11
Post-survey	0	0	32 (6)	47 (9)	21 (4)	3.89

The results in Table 2 address the Likert dimension of *human health and diseases*, *the use of hand sanitizers, vaccines, and antibiotics.* Of the five items in Table 2, there were two items (Items 3 and 4) that had statistically significant results. Item 3 was associated with the potential overuse (daily) of hand sanitizers and disinfectants; with a mean Likert score of 4.26 on the pre-survey, with very few of the respondents selecting Neutral (N), and the remining of the respondents equally choosing Agree (A) and Completely Agree (CA). The post-survey mean Likert score was 2.32 indicating a shift towards Completely Disagree (CD) and Disagree (D) with overuse of hand sanitizers ($p < 0.05$).

The use of hand sanitizers was addressed in Item 3. In the pre-survey, 84% believed hand sanitizers were beneficial to be used on their hands and surfaces on a daily basis; while in the post-survey only 27% believed that the use of hand sanitizers was beneficial. Antibiotics used for viral infections was addressed in Item 4. In the pre-survey, 47% favored the choices of Agree (A) and Completely Agree (CA) versus 42% choosing Completely Disagree (CD) and Disagree (D); this is a 5% difference in these responses. It is of interest to note that 11% in both the pre-and post-survey chose Neutral (N).

Item 4 dealt with the use of antibiotics for viral infections. The mean Likert score on the pre-survey was 2.84, with most of the respondents selecting Agree (A) and Completely Disagree (CD). The post-survey mean Likert score was 1.63, showing a significant shift towards Completely Disagree (CD) ($p < 0.01$), indicating that the respondents understood that

antibiotics are not appropriate for treatment of viral infections. The results for Items one, two, and five were not statistically significant.
The positions represented in this dimension were very relevant to the lives of undergraduate students particularly because the dimension includes topics that, in this current time (2019-2023), are controversial and opinionated. By and large, students overwhelmingly chose Neutral (N), more frequently for responses recorded in Table 2, than for data presented in any of the other tables. Item 2 of the post-survey involved students' opinions on whether 'government agencies should make it mandatory for vaccines to be administered ONLY for deadly human diseases.' Thirty-two percent of the students equally chose Agree (A) or Completely Agree (CA) and the other 32% chose Completely Disagree (CD) and Disagree (D); while 37% were Neutral (N) with this particular Item.

Item 5 addresses students' perceptions of a general issue in regarding governmental policy regarding government taxes to support research on certain bacterial organisms to improve human health. This change was not statistically significant, as 32% of the respondents were neutral for this item.

Research Question 2

The results of the initial and final Likert surveys, addressing Research question two *undergraduate students' opinions relating to topics addressed in a microbiology course* are presented in Table 3.

Table 3 Comparison of pre- and post-survey Likert scale responses to items in Section 3 for the dimension: *Prior knowledge of bacteria, viruses, and human diseases.*

Item 1. Based on my prior knowledge pertaining to microbiology, I believe that most bacteria on Earth are harmful to humans and cause disease. **

	CD	D	N	A	CA	Mean Score
Pre-survey	37 (7)	32 (6)	11 (2)	16 (3)	5 (1)	2.21
Post-survey	68 (13)	21 (4)	5 (1)	5 (1)	0	1.47

Item 2. Most viruses have the capability of living on surfaces and living in the air. **

	CD	D	N	A	CA	Mean Score
Pre-survey	5 (1)	16 (3)	11 (2)	42 (8)	26 (5)	3.68
Post-survey	47 (9)	37 (7)	0	11 (2)	5 (1)	1.89

Item 3. Using modern techniques of engineering, we should encourage engineers to develop microscopic robots that can enter into our cells to examine and eliminate pathogens. **ns**

	CD	D	N	A	CA	Mean Score
Pre-survey	0	11 (2)	63 (12)	21 (4)	5 (1)	3.21

Post-survey	0	16 (3)	47 (9)	37 (7)	0	3.21

Item 4. Antibiotics can cause secondary infections by killing good bacteria present in the human body. **ns**

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	32 (6)	37 (7)	32 (6)	4.00
Post-survey	0	5 (1)	5 (1)	47 (9)	42 (8)	4.26

Item 5. Misuse of antibiotics can lead to antibiotic resistance. *

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	11 (2)	47 (9)	42 (8)	4.32
Post-survey	0	0	0	37 (7)	63 (12)	4.63

The results of the data in Table 3 address the Likert dimension of human health and diseases: *Bacteria, viruses, and human diseases.* Of the five items in Table 3, three items (Items 1, 2, and 5) had statistically significant results. Item one involved student's prior content knowledge pertaining to microbiology and their knowledge concerning harmful bacteria and human disease; with a mean Likert score of 2.21 on the pre-survey indicating a position largely oriented toward the Completely Disagree (CD) and Disagree (D) range. The post-survey mean Likert score was 1.47 which indicated a shift largely toward the Completely Disagree (CD) range ($p < 0.01$). Item two was associated with the capability of viruses living on surfaces and living in the air; with a mean Likert score of 3.68 on the pre-survey, with most of the respondents selecting Agree (A) or Completely Agree (CA) range. The post-survey mean Likert score was 1.89 indicating a shift largely toward the Completely Disagree (CD) and Disagree (D) range ($p < 0.01$). Item five was related to the misuse of antibiotics leading to antibiotic resistance; with a mean Likert score of 4.32 on the pre-survey, with most of the respondents selecting Agree (A) and Completely Agree (CA). The post-survey mean Likert score was 4.63 with most of the respondents selecting the Agree (A) or Completely Agree (CA) range ($p < 0.05$). The results for Items three and four were not statistically significant.

For Item 1 of the post-survey, 89% of the undergraduate students reversed their position choosing the options of 'Completely Disagree (CD) and Disagree (D)' that 'most bacteria on Earth are harmful to humans and cause disease' indicating that they were better informed about the role of bacteria in the environment and human health. In the pre-survey, 68% of the students had a misconception and chose the options of 'Agree (A) or Completely Agree (CA)' to 'viruses have the capability of living on surfaces and living in the air.' However, in the post-survey, 84% held the scientific belief that viruses **do not** have the capability of living on surfaces and living in the air. Item 3, had the most Neutral (N) responses among all of the items with 63% in the pre-survey and 47% in the post-survey. Items 4 and 5 were associated with antibiotics. These Items seemed to captivate the students' responses with both the pre-and post-survey with Items 4 and 5 because, only one student chose Disagree (D) in both the pre-and post-survey.

Dimension 3 has five (5) Items dealing with infectious agents, pathogens, and control, and students' attitudes and knowledge related to them. Item 1 has to do with harmful versus

nonharmful pathogens. Item 2 is related to the transmission of pathogens. Item 3 deals with disease prevention. Items 4 and 5 is associated with the increased threat of resistance to antibiotics and the important side effects that the overuse of antibiotics can cause to human health

Research Question 3

The results of the initial and final Likert surveys, addressing Research Question Three pertaining to *how undergraduate students experienced virtual learning and computer-based learning in a microbiology course* are presented in Table 4. The results of the data in Table 4 address the Likert dimension of *attitudes and beliefs towards virtual learning and computer-based learning*. Dimension 4 has five (5) Items that addresses students understanding about the use of computer-based learning and interactive websites with respect to the importance of learning microbiology.

Table 4 Comparison of pre- and post-survey Likert scale responses to items in Section 4 for the dimension: *Attitudes and beliefs towards virtual learning and computer-based learning.*

Item 1. Computer-Based Learning (CBL) is a learner centered instructional method, in which computer software is used to deliver educational content to learners. How familiar are you with Computer-Based Learning (CBL)? *

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	5 (1)	47 (9)	47 (9)	4.42
Post-survey	0	0	0	37 (7)	63 (12)	4.63

Item 2. How familiar are you with utilizing the Center for Diseases Control and Prevention (CDC) website? *

	CD	D	N	A	CA	Mean Score
Pre-survey	21 (4)	16 (3)	16 (3)	42 (8)	5 (1)	2.95
Post-survey	0	0	0	11 (2)	89 (17)	4.89

Item 3. How familiar are you with utilizing interactive websites and computer simulations in your science/biology classes for learning? *

	CD	D	N	A	CA	Mean Score
Pre-survey	0	16 (4)	5 (1)	53 (10)	21 (4)	3.74
Post-survey	5 (1)	0	0	26 (5)	68 (13)	4.53

Item 4. How familiar are you with collaborating with your fellow students online? **

	CD	D	N	A	CA	Mean Score
Pre-survey	0	0	26 (5)	42 (8)	32 (6)	4.05
Post-survey	0	0	0	42 (8)	58 (11)	4.58

Item 5. How familiar are you with collaborating with your fellow students online while utilizing interactive websites and computer simulations? **

	CD	D	N	A	CA	Mean Score
Pre-survey	11 (2)	21 (4)	16 (3)	32 (6)	21 (4)	3.32
Post-survey	5 (1)	5 (1)	11 (2)	37 (7)	42 (8)	4.05

Of the five items in Table 4, all of the five items had statistically significant results. Item 1 was associated with how familiar undergraduate students were with utilizing computer-based learning (CBL); with a mean Likert score of 4.42 on the pre-survey, with most of the respondents choosing Agree (A) and Completely Agree (CA) range. The post-survey mean Likert score was 4.63 indicating a shift largely toward the Completely Agree (CA) range ($p < 0.05$). Item 2 delt with undergraduate student's experience with using the Center for Diseases Control and Prevention (CDC) website; with a mean Likert score of 2.95 on the pre-survey with most of the respondents selecting Agree (A). The post-survey mean Likert score was 4.89 indicating a shift largely toward the Completely Agree (CA) range ($p < 0.05$). Item three involved how familiar undergraduate students were with utilizing interactive websites and computer simulations for learning; with a mean Likert score of 3.74 on the pre-survey, with most of the respondents choosing Agree (A).

The post-survey mean Likert score was 4.53 indicating a shift largely toward the Completely Agree (CA) range ($p < 0.05$). Item four dealt with how familiar undergraduate students were with the advantages of collaborating with their fellow colleagues online; with a mean Likert score of 4.05 on the pre-survey with most of the respondents selecting Agree (A) and Completely Agree (CA). The post-survey mean Likert score was 4.58 indicating a shift toward the Completely Agree (CA) range ($p < 0.01$). Item five involved how familiar undergraduate students were with collaborating with their fellow colleagues online while utilizing interactive websites and computer simulations; with a mean Likert score of 3.32 on the pre-survey, with most of the respondents selecting Agree (A). The post-survey mean Likert score was 4.05 indicating a shift largely toward the Completely Agree (CA) range ($p < 0.01$).

The students predominantly Agreed (A) and Completely Agreed (CA) with Item 1 in both the pre-and post-survey. One student chose Neutral (N) in both the pre-survey, which shifted to zero in the post-survey. In the post-survey, there were zero responses for Completely Disagree (CD) and Disagree (D) in both the pre-and post-survey. For Item 2 of the pre-survey, 53% of students were not 'familiar with utilizing the Center for Diseases Control and Prevention (CDC) website.' However, the post-survey revealed that 100% Agreed (A) and Completely Agreed (CA) to becoming familiar with utilizing the CDC website. Item 3, of the pre-survey only 74% had prior experiences. However, after taking the class 94% had felt they were familiar in the post-survey. The most noticeable change with Item 4 was the pre-survey which had five.

Discussion

Some of the items of the Likert scales were intended to largely find out whether or not the students' positions changed after experiencing the online course including the online discussions

and presentation of information in the course. Other items based on scientific evidence were used to determine whether students better understood a scientific viewpoint presented in the online learning experience as opposed to less scientifically informed positions. Thus, the Likert items in Tables 1-4 contains two types of items: (1) general opinion items and (2) items based on scientific evidence.

The first Likert scale results (Table 1) addressed the student's orientation and attitudes toward the microbiology course; all of the items in this table consist of the general opinions of the students with respect to awareness of microbiology, human diseases and related topics. The students had a highly positive position in response to the items in the Likert scale presented in the pre-survey prior to the beginning of the course (Table 1). Therefore, given this positive orientation and attitudes at the beginning of the course, it would be very likely that the students would do very well with the outcome of the course. Overall, the students had a strong belief about the importance of ethical, legal, and social aspects of human societies (Item 3). Despite the prevalence of ethical, legal, and social implications (ELSI) research in the field of genomics as discussed in the course, the microbiology students had strong opinions contrary to established scientific knowledge such as "Coronavirus is a pathogen that causes the common cold" and "A mutated strain of the Coronavirus known as: "COVID-19 is a particular deadly strain that has killed, and continues to kill, humans." Another item arousing a strong response was "Should the United States government create a national database that can track people who have and have not received a vaccination for this deadly disease?" Moreover, the response to Item 3 summarizes the respondents' attitudes toward ELSI and its association with microbiology.

The results of the responses to items in the second Likert scale (Table 2) involves undergraduate student's opinions with respect to: 1) human health and diseases, 2) the use of hand sanitizers, 3) vaccines, and 4) antibiotics. The undergraduate students had mixed positions in response to particular items. Some of them showed very little change from the pre-Likert survey to the post-Likert survey (e.g., Items 1, 2, and 5 in the second Likert scale). However, Items 3 and 4 (Table 4) were of particular importance from the perspective of the rationale for this online course because they pertained to students' perceptions of utilizing interactive websites and computer simulations in science/biology classes and familiarity with collaborating among fellow students online. These particular items had the largest change in responses, compared with the other items in Table 2 (Items 1, 2, and 5) that largely addressed general opinions. Items 3 and 4 were based on scientific evidence dealing with sanitizers and disinfectants being used on our hands and surfaces on a daily basis (Item 3) and antibiotics used for viral infections (Item 4). For both of these items, undergraduate students began with a very diverse position. For example, some (47%) agreed in the pre-survey; and finally, only 11% agreed in the post-survey. Overall, in this survey, the majority of responses moved from Agree (A) and Completely Agree (CA) responses in the pre-Likert survey toward the Disagree (D) and Completely Disagree (CD) response in the post-Likert survey. A previous study by Gharpure et al. (2020) reported that participants within the same age range showed that the use of hand sanitizers increased during the COVID-19 pandemic and that there were gaps in the level of knowledge that the participants exhibited associated with use and misuse of hand sanitizers. However, these participants had a positive attitude toward the use of hand sanitizers and hand hygiene. Compared to the other survey results tabulated for this study, the data in Table 2 particularly had the most Neutral (N) responses in the pre- and-post survey,

suggesting that undergraduate students held ambivalent opinions and attitudes with respect to this dimension.

With respect to the third Likert scale (Table 3), Items 1, 2, 4, and 5 were related to bacteria, viruses, and human diseases, dealing with positions that have a scientific basis; while Item 3, involves student's general opinion. Item 1 states *"Based on my prior knowledge pertaining to microbiology, I believe that most bacteria on Earth are harmful to humans and cause disease.*" The purpose of this item was to assess students' understanding of misconceptions related to bacteria, in general. The results for Item 1 indicates that the undergraduate students had a significant level of prior content knowledge for the topic addressed in the item, demonstrating that they were aware that most bacteria on Earth *are not* harmful and *do not* cause disease. The results for Items 2 and 5, indicated that in the pre-survey, undergraduate students had prior misconceptions pertaining to viruses and antibiotic resistance. The results in the post-survey indicated that undergraduate students acquired a better understanding of these scientific concepts after the completion of the course. There were major gains in the responses to Item 2 from the pre-survey to the post-survey. At the pre-survey, 68% of the respondents believed that viruses have the capability of living on surfaces and living in the air; to 16% in the post-Likert survey understanding that viruses *do not* have the capability of living on surfaces or living in the air.

The results for Item 5 showed a significant gain from the pre- to post-Likert survey, with 89% of the respondents believing that misusing antibiotics can lead to antibiotic resistance initially; to 100% in the post-survey understanding that misusing antibiotics *will* lead to antibiotic resistance.

The research of Briggs et al. (2017) also provided insight into undergraduate students' misconceptions of viruses and antibiotic resistance in an introductory microbiology course; revealing that undergraduate students in general, have misconceptions with the topics of human health and microbiology. Misconceptions such as "prior exposure is required to acquire antibiotic resistance" (p.7) and "vaccines must cause disease in order to work" (p.8).

The fourth Likert scale (Table 4) involves undergraduate students' attitudes and beliefs towards virtual learning and computer-based learning. The students had very high and positive responses to these items as indicated by the increase in all of their post-mean scores (Table 4). This could be attributed to the fact that all the participating undergraduate students possessed a good level of computer-based learning skills as indicated by the on the positive evidence in the pre-Likert scale survey (Table 4). Particularly Item 1, where they selected largely Agree (A) and Completely Agree (CA) demonstrating that they had a high level of familiarity with computer-based learning. Likewise for Item 4, they also chose Agree (A) and Completely Agree (CA) indicating that they were familiar with collaborating with their fellow classmates online.

Limitations

Although the results of this study provide some new insights with statistically significant results, the current study has limitations. Firstly, this study was conducted when the COVID-

19 pandemic caused colleges and universities to shift from formal face-to-face learning to virtual learning around the world, particularly in the United States where the study occurred. This, in turn, may have influenced the students' mental state and their attitudes towards learning virtually. Second, there were no student interviews that were conducted to obtain possible evidence of changes in their understanding expressed in their own words, particularly what each undergraduate student felt was challenging.

Also, from time-to-time, it seemed that some undergraduate students had a limited attention span when using the online learning. For example, some people tend to "surf the internet" when they have access and become less focused on the content during their online learning. In a virtual setting, it is difficult to determine if a student is engaged, and this limits the level and quality of content information available to the researcher (Lodge & Harrison, 2019). Third, there was no qualitive data gathered in this study. Lastly, there was a relatively small sample size of participants for this study (n=19).

Conclusion

Virtual teaching and learning are conducted in many ways with different subject matter at different colleges and universities. Students are faced with some barriers with virtual learning/online learning such as:

- Technical: how to navigate through the course
- Administrative: signing up and/or approval for the course
- Collaboration: interacting with fellow students and instructor in a chat or break room
- Task orientation: pacing, organizational, and time management skills
- Technology: Internet availability

During the COVID-19 pandemic lockdown, classes nationwide shifted from face-to-face to online teaching and learning in the United States, beginning in March of 2020 and lasting under two years. This present study was conducted to inquire about the knowledge and opinions about topics in a microbiology course among undergraduate students' who majored in biology, and how they experienced computer-based learning in the microbiology course. Specifically, the focus of this study was on the experiences that undergraduate students had with utilizing computer-based learning and virtual learning in a microbiology course, and how the COVID-19 pandemic impacted their learning by sampling their opinions using a 5-point Likert scale survey. These undergraduate students are generally familiar with formal/face-to-face learning, which generally enhances the educational and social transmission of content knowledge (Banerjee and Rai, 2020), and may have further influenced their responses to, and achievement in, learning microbiology online.

With the sudden paradigm shift to online learning, away from the face-to-face pedagogy, many educators and students are questioning whether the implementation of online learning will continue to persist in the post-pandemic era.

The future of undergraduate education depends highly on colleges and universities to effectively implement computer-based learning, virtual and/or hybrid teaching and learning, and more

positively acclimating undergraduates with interactive and engaging websites and learning modules (Lapitan et al., 2021). Online pedagogy and learning in a virtual environment still provides many advantages for undergraduates, including, reducing travel time to-and-from college, traveling expenses, and is accessible 24/7; and, therefore, makes teaching and learning separable via learning management systems (Seitz 2021; Biel & Brame, 2016; Sánchez-Angulo et al., 2021; Olivet et al., 2016).

By analyzing the results of this research, there are some challenges and benefits of virtual learning that are highlighted. Instructors and students continue to struggle with the challenges of virtual learning and digital literacy (Lischer et al., 2021). Some of the challenges for instructors include the transition from teaching face-to-face to online, communicating, and pedagogical styles. While the challenges for students include technical skills for online learning, engagement, and participation. Challenges associated with the colleges/universities include audio/visual problems, technical troubleshooting, software availability, and utilizing learning management systems). This gap is seen across the world and between various levels of income within countries. For example, many educators are challenged with students not having the reliable infrastructure to keep up with learning and also acquiring the digital skills needed to provide quality education (Dalipi et al., 2022). Furthermore, virtual learning can cause vast difficulties for both students and teachers alike.

Students often become less ambitious and/or hesitant to participate in virtual collaboration; while educators, have to invest time preparing to upload documentation, videos, lectures, and encourage student engagement (Szopiński & Bachnik, 2022). Another challenge that students face, is the lack of face-to-face feedback and direct communication, which has been known to cause students to feel isolated and overwhelming frustration (Briggs et al., 2017).

Virtual online learning has the potential to increase undergraduate students' engagement, which in-turn, supports and facilitates learning in the online learning environment. This learning environment will ultimately provide undergraduate students opportunities to engage in a digital, creative, meaningful, and modern online experience to prepare and acclimate them for the future digital world.

Overall, with respect to the results of this study, the change in students' responses from pre-to-post survey were positive with regards to their opinions towards learning about microbiology and human diseases using the online course (Table 1); the use of hand sanitizers and their understanding of the use of antibiotics (Table 2); bacteria and human disease, viruses and capability of living on surfaces and in the air, and general concepts of antibiotics (Table 3); and utilizing computer- based learning and utilizing the Center for Diseases Control and Prevention (CDC) website, utilizing interactive websites/computer simulations and collaborating with their fellow students virtually (Table 4).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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