USING SCENARIO PLANNING TO TEACH PRE-NURSING UNDERGRADUATES ABOUT MANAGING ANTIBIOTIC RESISTANCE

by

Antonia C. Mac Crossan, B. S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Biology
December 2021

Committee Members:

Julie F. Westerlund, Chair

Robert J. C. McLean

M. Greg Abel

ACKNOWLEDGEMENTS

I am deeply grateful to Texas State University's Graduate College and College of Science and Engineering for all of the opportunities they have helped to bring me over my years at Texas State. The Department of Biology has been incredibly supportive and I am indebted to Dr Dittmar Hahn, Gloria Rodriguez, Celina Martinez, and Shane Pierce for all their help. My committee, Dr Julie Westerlund, Dr Bob McLean, and Dr Greg Abel, are some of the most wonderful and inspiring people I have met, and I couldn't have gotten close to this point without their guidance, reassurance, and expert teaching. Likewise, I wouldn't have made it through without the help of Michael McClellan, whose mathematical and R skills more than make up for my deficits, and who was an excellent code-reviewing partner. Dr Kristy Daniel started me on this path and I am grateful for her support, and the support of all the Daniel lab members I've befriended along the way (Dr Jenn Idema, Dr Zach Nolen, Bria Marty, Sara Salisbury, Victoria Reyes, Ryan Ament, Ryan Spencer). Dr Abel deserves a second thank-you for allowing me to completely hijack his lab curriculum and test out all kinds of crazy teaching techniques on his students.

My family have made this dream possible and not only would I not exist without them, but neither would this thesis. Mom, Dad, and Helena: you are my anchors. Thank you for motivating me and keeping me from giving up when things felt impossible. Eternal gratitude to Joseph Plappert for sitting in the library with me for hours writing side by side with me and keeping me sane. My friends—especially my grad mentors, like Danny Guerra, Jackie Tliemat, and Rebekah Rylander—are the best people in the world. Thanks for the Bardic Inspiration.

Thanks are also in order to the generous donors who have helped to fund my education: the Houston Livestock Show and Rodeo, the Texas State Graduate College, the family of Gwen S. Durrenberger, the family of Lamar and Marilyn Johanson, the family of George H. Meyer, and the family of W. E. Norris.

Lastly (but certainly not least-ly) I owe a great deal to all the students I have had the fortune to interact with over the last three years of teaching—not just the kind participants in this study, but everyone who has had to sit and listen to me gush about biofilms and plasmids and evolution and all sorts of things that weren't on the test.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

ABSTRACT

Pre-nursing undergraduates in the United States are required to take microbiology courses before they can apply to nursing schools, but newly graduated nurses in the US do not demonstrate a high knowledge of microbiology and related concepts, such as infection control, antibiotic resistance, and antibiotic stewardship. In order to mitigate this problem before students enter the clinical environment, new interventions must be introduced in microbiology courses to ensure students learn key microbiology concepts that can help them become better nurses. In this study, I wanted to evaluate pre-nursing undergraduates' knowledge about antibiotic resistance, measure the changes in this knowledge before and after different types of instruction, and understand how students utilized a scenario planning-based activity in order to learn about antibiotic resistance. I designed a curricular intervention involving scenario planning in order to encourage pre-nursing students to think about how the antibiotic resistance crisis is expected to evolve over the next twenty years, and to consider their role in changing its impact on patients. To test the efficacy of this intervention, I first collected pre- and post-lab questionnaires testing students' knowledge of infection control, responsible antibiotic use, and antibiotic resistance in a control semester, in which the scenario planning intervention was not given. I then compared the data collected in the control semester to data collected using the same questionnaire tool in an experimental semester, in which all students participated in the intervention. Quantitative data measuring students' correct responses to multiple-choice questions in the questionnaire were compared statistically using two-tailed *t* tests, and qualitative data evaluating students' rationales behind their answers to these multiple

choice questions were coded and compared descriptively. No significant quantitative differences were found between the control and experimental groups, but the conclusions drawn from qualitative data allowed me to better understand students' misconceptions about antibiotic use and resistance and the way those misconceptions fit into students' frameworks of scientific knowledge gained from coursework. I was also able to collect evaluation data that will help me to refine the educational intervention for future use.

I. INTRODUCTION

Antibiotic resistance has become a global health crisis as antibiotics are misused and overused, leading to the emergence of multidrug-resistant pathogens which contribute to increased mortality from bacterial infection (Michael et al., 2014; Ventola, 2015). Many of the factors driving this emergence are caused by humans, including overuse of antibiotics, over-prescription by healthcare professionals, noncompliance to prescriber orders by patients, and agricultural use (Michael et al., 2014; Stallins & Strosberg, 2020). Like other anthropogenic global change events, antibiotic resistance is difficult to manage and has significant social justice implications. It is inherently tied to climate change, perhaps a more well-known anthropogenic crisis, as a process, as changing global temperatures and weather patterns modify not only the rate of mutation in prokaryotes, but the incidence and range of several human pathogens (Harring & Krockow, 2021; Rodríguez-Verdugo et al., 2020). The urgency with which we approach mitigating climate change should be applied to mitigating antibiotic resistance, as the economic impact is estimated to be equivalent by 2030, and its impact will be just as great in terms of people affected (Burnham, 2021; Harring & Krockow, 2021).

Human behaviors regarding healthcare practices may be addressed through educational efforts, as health literacy and public understanding of antimicrobial therapy in the United States is already low (Edgar et al., 2009; Nisbet & Glick, 2008; Rikard et al., 2016). Antibiotic stewardship programs have been introduced in the last three decades in hospitals around the world in order to curb the spread of antibiotic-resistant bacteria (Doron & Davidson, 2011). These require input from various health practitioners to prevent antibiotic abuse and misuse before and after prescription. The role of nurses is rarely officially well-defined despite their close involvement in patient care and education (Merrill et al., 2019). However, staff nurses' roles in patient admission, safety, monitoring, and education all make nurses critical components of any healthcare institution's antibiotic stewardship plans (Olans et al., 2016). However, they lack the tools needed in order to fully participate in ASPs.

Background of the Problem

Nursing education is a rapidly changing field. Concept-based curricula, which focus on the relationships between concepts in order to help students transfer concept knowledge to the real world, are being introduced in many undergraduate programs in order to help students transition from education to practice while emphasizing active learning and critical thinking techniques (Baron, 2017; Stern et al., 2017). Concept-based curricula have been recommended for nursing education in order to help students think critically and generalize their knowledge to clinical settings since the turn of the millennium (Brussow et al., 2019; Lasater, 2011; Lewis, 2014). Even so, changes to nursing education have been limited by several barriers defined by Hendricks & Wangerin (2017), namely faculty's lack of knowledge about teaching conceptually, their fear of losing a unique identity, and resistance to collaboration and change. Because this requires a significant academic culture shift, instituting conceptual teaching in a lab setting, where instructors are typically younger and more malleable, may help pre-nursing students face the challenges of content oversaturation.

Nurses play a significant role in patient outcomes during antibiotic treatment (Ha et al., 2019). However, practicing nurses continue to indicate only low to moderate understanding of antibiotic stewardship, infection control, and antibiotic resistance (Monsees et al., 2017; Sodhi et al., 2013). Incidence of emerging diseases such as COVID-19 and the increasing demand for nursing professionals are exacerbating this knowledge deficit, as nurses entering the workforce feel overwhelmed and unprepared for the complexity of the clinical environment (US Department of Health and Human Services, 2017; Willman et al., 2020). The COVID-19 pandemic, in particular, has negatively affected nurses' involvement in antimicrobial stewardship around the world as personnel are shifted to the more critical role of dealing with the virus and its aftermath, despite the unique stewardship problems a pandemic can bring (Courtenay et al., 2020; Martinez et al., 2019). Very few undergraduate nursing programs sufficiently cover antibiotic resistance mechanisms and antibiotic stewardship principles (Courtenay et al., 2019). If traditional methods of instruction are not preparing nurses adequately for their careers in healthcare, changes must be made and new instructional techniques should be examined in order to ensure better future patient outcomes.

Further education for nurses is required to ensure they have the knowledge and skills required to improve patient outcomes in infectious disease cases. Nurses' understanding of how antibiotic resistance occurs and how the spread of resistance can be managed is critical, and can be supplemented through the use of new, concept-based curricula which use active learning techniques to enhance nursing students' understanding of their role in antimicrobial stewardship.

This antibiotic stewardship education must begin in undergraduate pre-nursing programs. While these programs often require some coursework about microbiology, many are dropping microbiology courses, especially at the associate degree level (Norman-McKay, 2018). In the UK, only 0.4-2.4% of time spent in pre-nursing programs is spent learning biological sciences in general, despite pre-nursing and nursing students continuing to demonstrate low understanding and high anxiety about microbiology and the biological sciences (Perkins, 2019; Taylor et al., 2015). De-emphasizing microbiology in pre-nursing education can leave students ill-prepared for dealing with patients, especially when answering patients' questions about infection control (Clancy et al., 2000). Still, even when microbiology is taught as part of the pre-nursing curriculum, students may get bogged down in memorizing facts about content, rather than realizing the opportunity to use concepts in microbiology to galvanize their understanding of disease and its treatment (Giddens & Brady, 2007; Kantor, 2010). Nurse educators now face the prospect of making significant changes to their course content and pedagogy to ensure their students gain not only the knowledge presented in their courses, but the skills to use it, including the practices of problem-solving and reflexivity (Baron, 2017; Pardue et al., 2005). The demands on healthcare in the United States as a whole is changing, and along with it, so is the role and responsibilities of nurses. While nursing education remains outdated, today's nursing students must prepare for more self-managed work, as more nurses work more independently in telemedical settings for both providers and insurance companies (Fraher et al., 2015).

The Inclusive STEM Education to Enhance (I SEE) Project is a European Union-funded partnership founded to design teaching strategies for STEM education, with emphasis on global citizenship, future-scaffolding, and creative thinking. So far, I SEE has created teaching modules on climate change, quantum computing, and artificial intelligence which have been implemented in secondary schools in Europe (Branchetti et al., 2018). I SEE modules are structured around topics which are future-oriented, complex, relevant, and glocal (addressing global issues with local consequences) (Fantini et al., 2019). These requirements make the antibiotic resistance crisis a perfect fit for an I SEE module, especially in a revised pre-nursing microbiology curriculum that shifts students' focus from memorization of content toward understanding of concepts.

Already, emphasis on future-scaffolding is used in science education, from the I SEE Project to secondary science education, especially through scenario planning activities (Cloud-Hansen et al., 2008; Jones et al., 2012; Paige & Lloyd, 2016). Scenario planning can allow students to better picture their roles in their future careers (Angheloiu et al., 2017). Scenario planning begins on the foundations of uncertainty, flexibility, and complexity and proceeds in three general stages—preparation (in which driving forces are identified), development (in which capability and options are evaluated), and use (in which actions can be taken) (Bouhalleb & Smida, 2020). This can facilitate learning, especially for non-experts, by presenting information in a narrative format. When a scientific issue can be recalled by a student by thinking of themselves as a "character" in a "story", the issue becomes more memorable (Chermack, 2004). When scenario planning exercises are based around backcasting (that is, imagining an endpoint, then working backward to bridge the gap between now and that endpoint), this method of education becomes even more appropriate. Because backcasting focuses only on steps toward a *desirable* future, not a likely future, it is able to encourage imagination beyond the confines of accepted reality (Höjer & Mattsson, 2000). This is especially beneficial when discussing generally bleak topics such as climate change or antibiotic resistance, in which experts and non-experts alike can become mired in negative thoughts about how hopeless solutions to current problems may be. Backcasting for scenario planning is more of a social form of learning than a scientific one—it is based around discourse, imagination, and optimism, making it especially useful for non-expert stakeholders in a contentious issue (Robinson, 2003).

The rate at which antibiotic resistance develops does not prepare health professions students to enter the workforce with up-to-date knowledge. For example, resistance to new antibiotics can be identified even within the first year of an antibiotic's use, as in the case of ceftazidime-avibactam resistance (Centers for Disease Control and Prevention, 2019). Thus, the information about antibiotics that pre-nursing students learn at the time they take a microbiology or bacteriology course may be obsolete by the time they are in a position to use it. Medications that may have been recommended as first-line treatments for certain disease while a nursing student is taking a microbiology or pharmacology course may no longer be effective or recommended by the time that student is first able to see that disease in clinical practice. Experts are approaching antibiotic drug discovery and designing guidelines for prescription and administration of existing antibodies with ever-increasing urgency (Podolsky, 2018). What is regarded as a truth or a common practice may easily become outdated in the four years most nursing students require to earn their degree and enter the workforce, especially when microbiology and other biological sciences make up so little of the curriculum, and is presented so early on (Craft et al., 2013; McVicar et al., 2014).

Definitions

Antimicrobial stewardship – strategies to limit the use of antimicrobial agents to the minimum necessary spectrum and duration when indicated in order to reduce the development of antimicrobial resistance and improve patient outcomes in a healthcare institution (Doron & Davidson, 2011).

Backcasting – a scenario methodology involving imagining a future solution, then working backward to evaluate what steps could be taken to reach that solution (Bibri, 2018).

Glocal – global challenges with local consequences, which require coordinated, specialized local approaches to solve (Caena, 2014).

Reflexivity – meta-reflection; that is, understanding one's actions in context (Freshwater & Rolfe, 2001).

Scenario planning – a process in which decision-makers, under the assumption that the future is unpredictable, present possible scenarios concerning the future in order to analyze the problem experienced in the present (Amer et al., 2013; Burt & van der Heijden, 2003).

Literature Review

Critical Reflexive Framework

Utilizing the I SEE-style activity to educate pre-nursing students about the antibiotic resistance crisis and their role in antimicrobial stewardship requires a critical reflexive framework—that is, one which integrates dialogue, the questioning of assumptions, and decentering (Holmes et al., 2005). The intervention aims to challenge students to analyze issues like antibiotic resistance not only through the scientific frame of *how* it happens, but through sociocultural lenses to determine *why* it happens and how to mitigate it. The I SEE-style module promotes dialogue between students as well as imagining dialogues between themselves and future patients or the community at large. In order to think critically, students must be encouraged to engage in that dialogue and be given opportunities to examine real-world phenomena, like antibiotic resistance (Mangena & Chabeli, 2005).

Nurses should constantly practice reflexivity in order to assess the areas in which they require further knowledge and development, as well as to know when they need to ask for assistance, whether it be from patients or other healthcare professionals (Timmins, 2006). Reflexivity requires people to not only consider their prior experiences when planning for the future (as in reflective practice), but to also consider the sociopolitical context in which their experience and current practice occurs, and modify their behaviors based on this consideration (Freshwater & Rolfe, 2001). Reflexivity also allows people to achieve autonomy in decision making while continuing to monitor their own preconceived notions about ethics and practice. These skills are incredibly important for nurses entering the workforce, who must be able to reason quickly and rationally in clinical settings (Kuiper, 2002; Kuiper & Pesut, 2004). I SEE inherently encourages reflexivity through emphasis on social justice and global citizenship. These are both critical in the successful practice of nursing as nurses practice advocacy and bridge the interpersonal gap between patients and healthcare providers from a variety of backgrounds (Rains & Barton-Kriese, 2001).

The I SEE-style activity evaluated in this study inherently required students to question their assumptions about how antibiotics are used, how disease should be treated, and what antibiotic resistance is. It asks students to first, independently, work new information into their framework of understanding and think optimistically about the future. Then, students must work together and combine their frameworks of understanding, comparing and contrasting their views on what is possible and what is not. As students discuss these complex issues in small groups, they are encouraged to practice reflexivity in comparing their knowledge with the knowledge of others and determining where they stand in regard to understanding key concepts.

Foresight Process Framework

The I SEE activities in use by the I SEE partnership in Europe are designed around a foresight process framework described by Voros (2003) in reference to strategic planning. This framework utilizes a step-by-step method to use information in the present to infer how the future might appear.

Using this foresight process framework, students are asked to gather information by asking key questions, e.g. what is the current problem? What is a potential solution? Once these questions are asked and answered through reading about relevant topics, foresight work can begin. The data (in this case, the answers to the original questions) are ordered in a meaningful way, then interpreted to find connections between seemingly separate concepts.

Prospection, or using these interpretations to examine possible futures, is the next logical step.

Using the connections found during data analysis, one may build a tangible plan for the future. For example, a student reading about the problems posed by the use of antibiotics in animal agriculture (Chokshi et al., 2019) may find a connection between this use and the presence of antibiotics in wastewater, and this conclusion may lead the student to plan about what could be done over the next five years or more to stop the use of antibiotics in livestock. Throughout the process, students may use this framework to create a concrete, collaborative plan to shape the future, making up for the mistakes of the present.

I used this framework, alongside the examples set by the existing I SEE Project modules, to design a new I SEE-style activity covering antibiotic resistance, ensuring that the activity I created was similar enough to the modules created by the I SEE partnership to deliver similar results.

The I SEE Project and Other Scenario Planning Ventures

Because I SEE modules were designed to make sure science learning could be recognized as personally, socially, and professionally relevant, and to encourage critical and creative thinking (Fantini et al., 2019), using the I SEE Project's research to develop a new module was attractive in the context of preparing pre-nursing students for the future. Simulation instruction has long been used in nursing education to help students to apply theoretical knowledge to real-world scenarios, but these are focused on simulating current practices, rather than imagining future needs (Hayden et al., 2014). Simulations were incorporated into nursing education to deal with changes in nursing practice in the 21st century—teaching not only for competence, but for capability (Fraser & Greenhalgh, 2001).

I SEE modules aimed mostly to develop students' future-scaffolding skills, rather than specific knowledge domains in science. Researchers developing these modules split future-scaffolding skills into two categories: systemic-structural skills (building systemic views by organizing pieces of knowledge) and dynamical skills (navigating complexity with an appreciation for scope, whether that be local versus global, present versus future, or individual versus collective) (Fantini et al., 2019). For this reason, I believe it is important for students who intend to enter the nursing workforce to engage with similar learning activities. Nursing educators have identified the need for active learning activities that engage students with complexity and encourage independent thinking and autonomous decision-making (McMahon & Christopher, 2011; Mitchell et al, 2013). By ensuring a teamwork element was reserved in my adapted version—assigning students to groups of their peers—in order to incorporate collective decision-making skills, I further intended to simulate the clinical experience, in which nurses work in care teams to reach agreement on treatment plans (Reis Girondi et al., 2017).

Because antibiotic resistance is a dynamic process, and because critical thinking is a rarely addressed but desperately needed skill in nursing, an I SEE-style educational intervention is well-suited to a group of pre-nursing undergraduates who have little experience with the open-ended problem solving they will need upon entry into the workforce. By working in groups, students will be able to refine these critical thinking skills as a unit, which should have an impact on how well they work with others in a clinical setting—where the strength of a nurse's engagement in teamwork can significantly increase patient safety and decrease adverse events (Brock et al., 2013; Reid & Bromiley, 2012). A goal of the I SEE Project researchers, to decrease apathy and anxiety about the future in students, is also particularly helpful to nursing students, who are preparing to enter a taxing career and work culture in which mental health concerns are common (Aloufi et al., 2021).

Development of Socialization Skills in Nursing Education

Undergraduate coursework is not simply a vehicle for education, but an important component of socialization for young adults (Weidman, 2006). This is especially true of pre-professional education, including nursing education, in which future nurses are exposed to not only knowledge and practical skills, but values and perceptions related to their future careers (Saarmann et al., 1992). Nursing education should not only give students knowledge of anatomy, pharmacology, microbiology, and other scientific aspects of the profession, but should also impart critical thinking skills, respect for others, cultural understanding and awareness, and social responsibility as critical to students' roles as future nurses (de Swardt et al., 2017).

Educational interventions that highlight concepts such as social justice, for example, play an important role in allowing students to develop skills as patient advocates and exhibit empathy in medical practice, where nurses are often placed in contact with sensitive social situations as often as they are with medical crises (Caldwell & Cochran, 2018). The I SEE project aims to infuse science education as a whole with further analysis and awareness of the social aspects of complex scientific issues, encouraging students to seek out and listen to a diversity of perspectives, skills critical to careers in healthcare (Fantini et al., 2019). As students confront these issues, they must also be asked to confront their own assumptions and misconceptions in the process.

While antibiotic resistance may not at first appear to be a social justice issue, it affects marginalized communities at disproportionate rates. In countries like the United States, where healthcare can be prohibitively expensive even for the middle class, self-medication and going without care is the norm in people experiencing poverty and communities of color (Lescure et al., 2018; Mainous et al., 2008; Mills, 2016). Not only is pollution a major contributor to resistance, as it promotes more rapid mutation and horizontal distribution of antibiotic resistance genes, but it also is most common in developing countries and working-class communities worldwide. Pollution and antibiotic resistance are also projected to increase significantly alongside global climate change, and the implications of climate change too impact marginalized communities more than people belonging to privileged groups (Novo et al., 2013; Rodríguez-Verdugo et al., 2020). Climate change is also increasing the incidence and range of antibiotic-resistant human pathogens, which will disproportionately affect "climate refugees" who are forced to relocate due to negative effects of climate change such as rising sea level, increases in extreme weather, and famine (Barata Tavares et al., 2019; Casadevall et al., 2019; Rees et al., 2019). This makes antibiotic resistance a socioscientific issue, which means that when information about antibiotic resistance is presented in a classroom setting, it cannot and should not be removed from the context of its impact on global society (Friedrichsen et al., 2019). As such, addressing misconceptions about resistance is not only beneficial to students' understanding of microbiology and broader science, but also to their present roles in their communities and their future roles as healthcare providers and public health educators.

Teaching antibiotic resistance and stewardship as a socioscientific issue, rather than simply a scientific issue, helps students to better understand their role in a global whole. Exposing students to conversations about social impacts of public health issues and to critical discussions of social justice can help students to feel more a part of the communities they will practice in (Derreth & Wear, 2021).

Nurses experience anxiety upon entering the workplace when they are faced with the problem of patient education. Already, beginning nurses have largely grown up in a generation that has experienced a lack of development in interpersonal communication—now, they are expected to relate to others in a way that directly impacts their health outcomes (Chicca & Shellenbarger, 2018; Hagerty et al., 2017; Willman et al., 2020).

Critical Thinking in Nursing Education

Critical thinking and interpersonal communications have been requisites for nursing education since the early 1990s, but there have been barriers to teaching foundational skills in both categories—despite, as many nurse educators have pointed out, the fact that the components of critical thought closely resemble the steps of the nursing process (define the problem, plan, recognize assumptions about the problem, formulate a relevant hypothesis, and identify valid conclusions) and are thus important to newly graduated nurses' integration into the workforce (Boychuk Duchscher, 1999). In order to encourage critical thought, students and instructors must meet halfway. On the part of the instructor, a safe classroom climate must be set, in which no student feels awkward or uncomfortable bringing up their suggestions, and an open environment in which students can physically engage with one another must be planned (Bull et al., 1995). On the part of the students—who are used to engaging in largely traditional, lecture-based courses—they must prepare to modify the way they participate in the classroom setting, switching from a passive "follower" to an active "designer" of their learning experience (Gormally et al., 2011).

While instructors often attempt to introduce inquiry-based activities into their classrooms, they are often received poorly by students because they are unwilling to re-examine their classroom roles. This is especially true of younger, Generation Z students, who are typified by underdeveloped interpersonal and critical thinking skills (Chicca &

Shellenbarger, 2018; Hampton et al., 2020). As a result, even as educational environments are changing, students are experiencing difficulty learning and growing from these new experiences. Only 6% of college graduates in the United States can demonstrate critical thinking skills (Association of American Colleges and Universities, 2005), and newly graduated nurses feel most unprepared for skills requiring critical thinking (Walker & Rossi, 2021; Willman et al., 2021).

The Role of Nurses in Antibiotic Stewardship

Antibiotic stewardship programs are integral in ensuring positive patient outcomes, reducing healthcare-associated costs, and minimizing the development of antibiotic resistance in bacteria (Fishman, 2006; MacDougall & Polk, 2010). While commonly associated with hospitals, antibiotic stewardship programs are critical in combating resistance in communities at large by minimizing environmental exposure to antimicrobials and ensuring proper hand-washing and environmental cleaning standards are met, among other efforts (Owens, 2008). When implemented properly, antibiotic stewardship programs can help reduce patient mortality and the length of patients' stays in hospitals, as well as lower hospital spending on antibiotics (Akpan et al., 2016; Schuts et al., 2016).

Nurses are interested in learning more information about infection control, antibiotic resistance, and antibiotic stewardship, but demonstrate low competence in these topics (Rábano-Blánco et al., 2019). Nurses are in an ideal position to engage in antibiotic stewardship practices such as assessing patient allergy history, antibiotic dosing and sensitivity reporting, reviewing microbiological culture lab results (from which diagnoses can be drawn), and patient progress, and should absolutely be closely involved with antibiotic stewardship efforts (Centers for Disease Control and Prevention, 2017; Edwards et al., 2011). However, if their pre-service education leaves them with inadequate understanding of antibiotic use and resistance, nurses will not be well-equipped to participate in antibiotic stewardship programs. Even in the workplace, nurses are routinely left behind in regards to knowledge about their institutions' antibiotic stewardship policies (McCoy et al., 2018).

Existing Misconceptions About Antibiotic Resistance

Misconceptions about antibiotic resistance exist even in advanced students of biology and practicing healthcare professionals (Briggs et al., 2017; Richard et al., 2017). This extends even to the belief that while antibiotic resistance is a national problem, it is not a local problem, showing a gap in medical professionals' understanding of the impact of antibiotic resistance (Zetts et al., 2020). Misconceptions held by students about antibiotic resistance stem from incomplete understanding of the science behind it and the use of certain forms of intuitive reasoning, which is an informal way of thinking arising from a set of assumptions about the world (Coley & Tanner, 2015; Richard et al., 2017).

Many undergraduate students enter microbiology courses with preconceived misconceptions about antibiotic resistance, mainly centered around the vocabulary used in lessons, such as the differences between Gram positive and Gram negative bacteria (Stevens et al, 2017). Misconceptions relating to natural selection and evolution in particular are well-studied in undergraduate populations. Understanding natural selection is key to understanding how antibiotic resistance arises and spreads, and antibiotic resistance is often used as an example by instructors teaching evolutionary processes (Abraham et al., 2009; Cloud-Hansen et al., 2018). These misconceptions fall into several categories, described by Gregory (2009) as teleological (explanations based on purpose), anthropomorphic (attributing change to intentional actions of organisms or "Nature"), use & disuse (the Lamarckian view that using or not using a phenotypic trait relates to the trait staying in a population), "soft" inheritance (traits acquired over a lifetime can be passed down to offspring), absolutist (natural selection is a goal-oriented event), and essentialist (entire populations change rather than the proportion of genetic variation within a population). These misconceptions occur regardless of a student's "belief" in evolution or their prior knowledge about biological processes (Bishop & Anderson, 1990)—rather, they occur due to the complexity of underlying concepts, students' difficulty in grasping taxonomical relationships, and the scope of the time frame in which evolutionary processes occur (Ferrari & Chi, 1998). Misconceptions about evolutionary processes are students' strongest upon entry into microbiology courses, and have a negative impact on those students' ability to understand the biological basis for many microbiology concepts (Briggs et al, 2017).

In the allied health fields, many educational efforts concerning antibiotics and resistance have been made in pre-medical or medical programs, as well as continuing education for practicing doctors, despite the role of nurses and other healthcare professionals in the prescription and administration of antibiotics (Davey & Garner, 2007). This shows that pre-nursing education is being left behind in terms of addressing these misconceptions before students proceed to nursing schools and clinical practice. Incomplete knowledge of microbiology in pre-health professionals leads to riskier antibiotic prescribing behavior in clinical practice, with up to 68% of US antibiotic prescriptions described as 'sub-optimal'—that is, inappropriate for the patients' condition or ailing to treat the infection effectively (Charani et al., 2010). This is relevant for nurse practitioners, who have the power of prescription, and nurses who do not have the power of prescription but are in a position to review prescribers' orders and catch errors (Flynn et al., 2012).

Research Questions

This study aimed to investigate how undergraduate pre-nursing majors in a traditional microbiology course can utilize scenario planning embedded in an I SEE -style activity to better understand not only the development of antibiotic resistance, but how to implement this understanding in their future clinical practice. My experimental group worked collaboratively on an I SEE-style activity involving antibiotic resistance, whereas my control group did not. I believed that pre-nursing students' knowledge and understanding of antibiotic resistance and stewardship would roughly reflect that of the general population, which has proven low (Lee et al., 2003; WHO, 2015), and that students' open-ended rationales for their answer choices would likely reflect several misconceptions previously found in undergraduates regardless of major (Carter et al., 2016; Richard et al., 2017).

RQ1. What is the nature of pre-nursing students' understanding of antibiotic resistance and antibiotic stewardship?

RQ2. In what ways do pre-nursing students' knowledge of antibiotic resistance and antibiotic stewardship change upon completing the I SEE-style activity (experimental group) or not completing the I SEE-style activity (control group)?

RQ3. What is the difference in students' changes in understanding of antibiotic resistance between students who complete the I SEE-style activity and those who do not?

RQ4. How do students utilize the I SEE-style activity to learn about antibiotic resistance?

I hypothesized that understanding of antibiotic resistance would improve from pre-lab to post-lab in the experimental group, who completed the I SEE-style module, by a larger margin and more significantly than in the control group. I anticipated that students would appreciate the more active approach of the I SEE-style module, and learn more about antibiotic stewardship from interacting with their fellow students and being exposed to other perspectives.

II. RESEARCH DESIGN AND METHODOLOGY

In this chapter, I will describe the hypotheses, research instruments, selection of participants, and methods of data collection and analysis used in this study. This study had three purposes: namely, to ascertain what pre-nursing students already know about antibiotic resistance and stewardship (Research Question 1), to measure how that knowledge changes after instruction in relevant concepts (Research Questions 2 and 3), and to understand how pre-nursing students use an I SEE-style lab activity to explore antibiotic resistance as a socioscientific issue (Research Question 4).

Quantitative data was collected in order to measure, based on correctness of responses to a survey tool, the differences in students' knowledge about infection control, antibiotic resistance, and antibiotic stewardship. Quantitative methods were also used to compare students' confidence in their own knowledge after participating in the I SEE-style activity and another lab activity which was used as a control. Two-tailed *t* tests were used to determine significance of students' change in correctness before and after instruction.

Qualitative data was collected in order to isolate misconceptions held by students before and after instruction about antibiotics and antibiotic resistance. I wanted to compare the presence/absence of these misconceptions in student rationales given before and after lab activities, to determine whether the lab activities were effective in divesting students of these misconceptions or, conversely, introduced misconceptions that did not exist prior to instruction. We also used qualitative data to determine the status of students' knowledge and draw out trends in how that knowledge changes after instruction.

Pilot Study

To prepare for this research and to field-test the clarity and useability of the I SEE-style module, the module was first given to students in the Fall 2019 and Spring 2020 semesters enrolled in my lab sections. This was done as a supplement to the instruction received by all students enrolled in the course, and was not given as an extra, graded assignment. Students were informally asked after participating in the activity to give feedback on how the activity was delivered, and changes were made based on these students' suggestions. The researcher informally observed students' participation in the activity, and made notes about changes that needed to be made prior to testing the I SEE-style module as an educational intervention.

Observations made in this pilot study period allowed the researcher to create a rubric (Appendix B) for instructor evaluation of students' presentations and to refine the parameters of the assignment to encourage students to engage more deeply with the requirements of the assignment. Stricter language was thus implemented in the assignment and accompanying rubric to ensure students gave more serious suggestions and consulted more reliable sources of background information. The period in which students were asked to prepare their presentations was increased from 30 minutes to one week. Improvement in quality in student work was seen in the projects by greater detail indicating more effort and time into the Spring 2021 projects.

A major limitation of this pilot study was that it preceded the COVID-19 pandemic, and thus the changes to course delivery made to accommodate slowing the spread of the SARS-CoV-2 virus. All tests of the I SEE-style module, and thus all observations, were conducted in a fully in-person classroom setting. Data gathered for this study, on the other hand, was collected in a hybrid course format, with some students participating in person and some online, attending class via Zoom. As a result, students experienced unforeseen complications relating to working in groups partially or completely online, and to communicating with classmates with whom they had not previously interacted.

Research Design

This study comprised a pre/post survey design using mixed methods. This method was chosen to illustrate quantitative data about changes in percent correctness with more detailed observations on how students' rationales for correct and incorrect answers changed. Our quantitative data lent further credibility to our qualitative findings, as we were able to ascertain the significance of changes in students' responses to each item in our questionnaire. By combining these methods, we ensured that our data show a diversity of views—we are not only including our perspectives about participants' understanding of antibiotic resistance and stewardship through quantitatively comparing their scores, but we are allowing the participants' perspectives to shine through in our qualitative data as we preserve students' conceptions of their knowledge in their own words (Bryman, 2006).

Participants, Population, and Sample

Participants were all over the age of 18. The Institutional Review Board (IRB) of Texas State University approved all methods and procedures for this project. The data collected for this study was deidentified, and protected all human subjects participating in the project. There was no coercion or penalty for not participating. All students enrolled in the laboratory course were given the same educational materials to prevent any differences in learning outcomes and grade performance between study participants and non-participants. This study includes a total of 70 participants (34 in Fall 2020, 36 in Spring 2021), all pre-nursing undergraduates enrolled in the study course at Texas State University.

Recruitment was performed through Qualtrics, with reminders sent through the university's learning management site for the study course. The text of the recruitment message, consent form, and reminder messages may be viewed in Appendices D and E. The lab coordinator agreed that extra credit would be given to all participants completing the pre-lab questionnaires in both semesters (two points added to a lab quiz grade) and that further extra credit would be given (five points added to the lab final exam) upon receipt of completed post-lab questionnaires as incentive for students to participate in the study.

Upon receipt of surveys, each participant was given a pseudonym. Throughout this document, we will refer to each participant using that pseudonym.

Research Instrument and Data Collection

The questionnaire, called the Responsible Antibiotic Use Electronic Questionnaire (RAUEQ), used in this study was designed alongside Dr Robert J. C. McLean, an expert in microbiology providing construct validity, and Dr M. Greg Abel, the coordinator for the labs used in this study. The full text of the questionnaire may be found in Appendix A: Responsible Antibiotic Use Electronic Questionnaire. It was administered using Qualtrics and took approximately 30 minutes to complete pre-lab—the post-lab evaluation questions added about 15 minutes for response time for a total of 45 minutes. Five demographic questions were placed at the beginning of the survey in order to help the researchers determine how generalizable results could be to the general population and to ensure all participants chosen were a. over 18 years old, and b. pre-nursing majors. These demographic questions asked participants to declare their gender identity, racial identity, major, classification, and age. In the Spring 2021 semester, a quality control question was added to ensure quality of responses which asked students to select the word "resistance" from a list of four terms ("antibiotic", "mutation", "infection", and "resistance"). Only students answering the quality control question correctly were included in the study.

The RAUEQ was distributed electronically to all students enrolled in the study course, who were given periods of two weeks each to complete the pre-lab and post-lab questionnaire in both semesters. It was sent via Qualtrics, an electronic survey administered through Texas State University, to 237 students in the Fall 2020 semester and 241 students in the Spring 2021 semester. A breakdown of how many responses were gathered and accepted may be seen in Table 1. Responses were accepted if students met a set of criteria: a. age over 18 years old, b. majoring in pre-nursing, c. all questions answered, d. both pre- and post-lab questionnaires returned, and e. in Spring 2021, answered quality control question correctly. Students were reminded of their receipt of the RAUEQ via an announcement in the Canvas course learning management site after Qualtrics distribution.

Table 1. Number of responses received to the RAUEQ and number of responses meeting criteria for inclusion in the study.

Semester	**Pre- or post-**	**Responses received**	**Responses accepted**
Fall 2020 (control)	Pre-lab	119	34
	Post-lab	90	
Spring 2021 (experimental)	Pre-lab	95	36
	Post-lab	112	

Demographic data for students submitting acceptable responses and thus included in the study may be seen in Table 2 below. All demographic data were self-reported by the students and not verified by the researchers.

Table 2. Number of study participants included in demographic categories, by age, race, gender identity, and classification.

Semester	**Gender identity**			**Race**					**Age**			**Classification**			
	F	M	Other	White	Hispanic or Latinx	Black	Asian	Other	18-20	21-23	>23	Fr	So	Ju	Se
Fall 2020	34	1	0	18	11	3	1	1	32	2	0	0	27	7	0
Spring 2021	32	3	0	15	11	2	5	2	31	3	1	4	22	9	0

Eleven RAUEQ questions were written based on necessary competencies for nurses-in-training (Courtenay et al. 2019). Courtenay et al. defined six domains of knowledge critical to education of nurses in antibiotic stewardship practices: 1) infection prevention and control, 2) antimicrobials and antimicrobial resistance, 3) diagnosis of infection and the use of antibiotics, 4) antimicrobial prescribing practice, 5) person-centered care, and 6) interprofessional collaborative practice. We judged only the first four domains to be relevant to pre-nursing microbiology curriculum, and thus excluded domains five and six.

We created three RAUEQ questions in relation to infection control in domain one:

1. When should one remove disposable gloves in a clinical setting?
2. Which of the following is as effective as cleaning one's hands with soap and running water?
3. Which of the following is most effective in preventing droplet transmission of disease?

These questions require students to demonstrate an understanding of standard precautions in a healthcare setting and how to prevent and control infection (Courtenay et al. 2019).

We created three RAUEQ questions about antibiotic resistance in domain two:

4. Is antibiotic resistance an example of evolution?
5. How do mutations which can lead to antibiotic resistance happen in bacteria?
9. Which of the following can contribute to a rise in antibiotic resistance?

While Domain Two is concerned primarily with how misuse and overuse of antibiotics contributes to resistance (Courtenay et al., 2019), we added two questions (4 & 5) which are more relevant to the introductory microbiology curriculum used in the course studied. These questions were also intended to ascertain what misconceptions students had about the way antibiotic resistance arises in bacteria—misconceptions that have been previously studied in undergraduate students as they pertain to those students' understanding of natural selection and evolution (Bishop & Anderson, 1990).

Domain Three, diagnosis of infection and the use of antibiotics, provided us with questions about responsible prescribing and use of antibiotics:

10. Should a patient take the same antibiotic more than once?

11. Which of these is the only effective treatment for bacterial infection?

To answer these questions correctly, students must demonstrate an understanding of why antimicrobials are chosen in context, common side effects and sensitivity reactions to antibiotics, and quality and safety of prescriptions.

Finally, Domain Four, antimicrobial prescribing practice, was used to create questions relating more to prescribing practice:

6. When should a patient be prescribed antibiotics?

7. When should a patient stop taking antibiotics that are prescribed to them?

8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?

These questions require knowledge of guidance about completion of a course of antibiotics, types of antibiotic therapy, and major factors influencing the prescription of antibiotics.

Each RAUEQ item was a multiple-choice question, with choices selected to reduce response burden (i.e. difficulty in coming up with a response to a question about potentially unfamiliar concepts) in students who have not yet been exposed to the curricular material described in the questionnaire and written with consideration to possible most common responses based on my prior experience teaching this material to similar groups of students. Responses to multiple-choice items yielded quantitative data. In order to decrease the possibility of receiving responses selected at random, and to yield richer data concerning misconceptions about the concepts included in the questionnaire, each multiple-choice item was followed by a space in which participants could explain why they selected their answer choice. This free-response rationale section provided qualitative data.

Answers to multiple-choice questions in the RAUEQ were determined by the researcher to be correct or incorrect. These correct answers and the source materials describing them are summarized in Table 3 below.

Table 3. Rationale for determining which answer choice in each multiple choice item was 'correct' in the RAUEQ.

Question	Correct answer choice	Rationale
Q1. When should one remove gloves in a clinical setting?	D. All of the above are correct	Gloves should be removed "As soon as gloves are damaged (or non-integrity suspected)… When contact with blood, another body fluid, non-intact skin and mucous membrane has occurred and has ended… When contact with a single patient and his/her surrounding, or a contaminated body site on a patient has ended… When there is an indication for hand hygiene" (WHO, 2009, p. 2)
Q2. Which of the following is as effective as cleaning one's hands with soap and running water?	D. None of the above are as effective as cleaning one's hands with soap and running water	"Soap and water are more effective than hand sanitizers at removing certain kinds of germs… although alcohol-based hand sanitizers can inactivate many types of microbes very effectively when used correctly, people may not use a large enough volume of the sanitizers or may wipe it off before it has dried…" (CDC, 2020)
Q3. Which of the following is most effective in preventing droplet transmission of disease?	C. Wearing a disposable or washable mask which covers the nose and mouth	Recent studies examining prevention measures against SARS-CoV-2, and public health messaging students have been exposed to throughout the COVID-19 pandemic (Chong et al., 2021; Wang et al., 2021)
Q4. Is antibiotic resistance an example of evolution?	A. Yes	General consensus in the scientific community (Aminov, 2009; Davies & Davies, 2010)
Q5. How do mutations which can lead to antibiotic resistance happen in bacteria?	B. As a result of random chance	General consensus in the scientific community (Svensson & Berger, 2019)
Q6. When should a patient be prescribed antibiotics?	C. When they are diagnosed with a bacterial infection	Centers for Disease Control guidelines (CDC, 2021a); recommendations by members of the American Medical Association (Colgan & Powers, 2001)
Q7. When should a patient	A. When their prescription runs out or	Patient education materials published by the Centers for Disease Control (CDC, 2021b)

stop taking antibiotics that are prescribed to them?	they are instructed to stop by their prescriber	
Q8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?	A. Wait until the exact cause of infection is identified before starting a narrow-spectrum antibiotic	Centers for Disease Control's antibiotic prescribing guidelines for healthcare professionals (CDC, 2020); reviews of drivers of antibiotic resistance (Friedman et al., 2016)
Q9. Which of the following can contribute to a rise in antibiotic resistance?	D. All of the above	Article given as assigned reading to students in study population (Ventola, 2015)
Q10. Should a patient take the same antibiotic more than once?	A. Only as long as they do not show sensitivity to the antibiotic	Antibiotic prescribing guidelines used in both the United States and European Union member nations (Dyar et al., 2016; Fluent et al., 2016; Smith et al., 2018; Suda et al., 2016; Petersen & Hayward, 2007)
Q11. Which of these is the only effective treatment for bacterial infection?	D. All of the above may be used to effectively treat bacterial infections	Reviews of research into non-antibiotic treatment of bacterial infections (Opal, 2016; Rex et al., 2019); textbook assigned to students in study population (Totora et al., 2016)

In the post-lab RAUEQ, a ten-item evaluation tool was included, adapted from that used by Branchetti et al. (2018) in their evaluation of the I SEE project. These questions used a Likert-style scale approach to ascertain how highly students would rate their knowledge and understanding of key concepts (how antibiotic resistance arises, appropriate use of antibiotics in healthcare, and efforts to slow/stop the occurrence of antibiotic resistance) found in the four domains and their confidence in explaining these key concepts and articulating a strategy to solve a problem. Students were also asked to rate their overall experience with the lab activity, and given open-ended questions in which they could explain the effects of the lab activity on their understanding of key concepts and the activity's perceived usefulness ot the student's future career.

Educational Intervention - I SEE-style activity

In Fall 2020, the I SEE-style activity, an educational intervention, was not given to students enrolled in the study course, as this was to be used as a control semester. Students engaged in the lab activity in the same manner as previous semesters: by performing Kirby-Bauer assays to test the susceptibility of different species of bacteria to various antibiotic drugs and household germicidal compounds. Students were asked to evaluate these assays by measuring zones of inhibition for each drug and compound tested and comparing them to a table of susceptibility standards. Readings were given on the antibiotic resistance crisis (Ventola, 2015) and the concept of complexity as it relates to healthcare (Sturmberg & Martin, 2009). Students were expected to summarize these readings briefly in a graded pre-lab homework assignment.

In Spring 2021, students were asked to participate in the same Kirby-Bauer assays, but were also given the I SEE-style activity, which was designed by the researcher to engage students in the process of scenario planning. The I SEE-style activity handout, as well as the rubric instructors were given to evaluate the activity, is included in Appendix B: I SEE-Style Activity. The I SEE-style activity was given as part of the regular lab curriculum, and students participated regardless of whether they were participants in the study or not. There were 12 Instructional Assistants (IAs) assigned between 15 lab sections, and all IAs were trained in how to deliver the assignment to the students the week before it was given in a regular meeting with the lab coordinator. All IAs were supplied with the document and rubric (Appendix B) to be given to their students, as well as a three-minute instructional video recorded by the researcher to explain the day's lab activity. All IAs were instructed to upload these materials to the lab's Canvas learning management site one week prior to the lab activity. Both the Ventola (2015) and Sturmberg & Martin (2009) readings were again assigned to students, as in Fall 2020, and students were asked to briefly summarize each article as part of a pre-lab homework activity. In addition, the final question of the pre-lab activity asked students to begin imagining an antibiotic resistance-free future:

> Based on what you have read, imagine a world free of antibiotic resistance bacteria by the year 2041. What has happened between now and them to make this happen? Placing yourself in the position of a politician, healthcare worker, scientist, or other stakeholder in this future, describe what measures were taken by society over twenty years to effectively end antibiotic resistance.

After the completion of the Kirby-Bauer assay activity, IAs initiated the first phase of the I SEE-style activity by having students consider some of the answers given to the above discussion question in the pre-lab homework. IAs screened student responses to this question and provided several for class-wide discussion by either writing selected (anonymized) responses on the chalkboard or displaying them on a PowerPoint slide. IAs were told to lead students in talking about how reasonable, realistic, and affordable each of the selected responses might be and encourage students to form groups of two to four in order to select a response and investigate further the proposed policy changes or other intervention(s) described in that response for their project. One week was given to work on the I SEE-style project before in-class presentations. Students were told to meet remotely using email, GroupMe, and Zoom videoconferencing over the week in order to discuss their presentations. Peer reviews were required from each group to catch "social loafing"—that is, to penalize students who did not put in the same amount of work as their groupmates.

Students were given considerable leeway in how their projects were presented, but all projects had to be given to the rest of the class for peer evaluation. Students could give simple oral presentations, create videos or PowerPoint presentations, or use another method of delivery to present their projects. During the in-class presentation, IAs evaluated each project according to the rubrics (Appendix B) supplied to them.

Qualitative Analysis

Qualitative analysis proceeded in two stages: descriptive coding and pattern coding. In essence, coding is a process of using assigned labels (codes) to describe what a selection of non-numeric data are about (Saldaña, 2015, p. 3). This is an inherently interpretive and subjective method of analyzing qualitative data, and thus requires some measure of reliability. The goal of coding this data is to find meaningful patterns in qualitative responses, and to compare the frequencies of these patterns between sets of responses in order to draw conclusions about the similarities and differences in students' shared experiences. Codes are not mutually exclusive—often, codes may overlap and a given quotation may have multiple codes and represent multiple themes.

Descriptive coding "summarizes in a word or short phrase—most often as a noun—the basic topic of a passage of qualitative data (Saldaña, 2015, p. 88)." This method was used because it is simple and gives rich descriptions of qualitative data that are easy to connect to the text. Pattern coding involves using

> explanatory or inferential codes, ones that identify an emergent theme, configuration, or explanation. They pull together a lot of material into a more meaningful and parsimonious unit of analysis (Miles & Huberman, 1994, p. 69).

The codes initially found during descriptive coding were analyzed for conceptual similarity. Codes which were similar were grouped into one pattern code (e.g. each code mentioning a concept covered in introductory biology curriculum, such as "natural selection", "horizontal gene transfer", and "heritability", were placed under the pattern code "foundational learning"). Not all pattern codes were broad enough to be classified into themes in the second cycle of coding, but many were.

During the second stage of the coding process, the researcher and a research assistant refined codes together and created a consensus. Consensus was achieved through simultaneous coding, creating a codebook of common themes and recurring themes (Appendix F), and meeting to discuss and challenge any discrepancies between codes and the codebook. If discrepancies occurred, we discussed the codes in context of the data and developed a consensus. In all cases, a consensus was eventually reached, and no further action was necessary. The reliability of our categorization of the qualitative data was measured using Cohen's (1960) kappa, which allowed us to determine whether our agreement on codes was greater than the proportion of expected agreement, and thus was non-random in nature (Warrens, 2015). This value, $\varkappa = 0.614$, indicated substantial agreement between researchers in code classification and definition. Note-taking and discussion of codes and overarching themes helped to formalize the definitions of concepts as they emerged in the data.

III. RESULTS

This section begins with a summary of results, which sorts the most relevant data to our research questions. A full presentation of qualitative and quantitative results follow this summary.

Summary of Results

Based on the survey data, the following research questions will be answered in this section:

RQ1. What is the nature of pre-nursing students' understanding of antibiotic resistance and antibiotic stewardship?

RQ2. In what ways do pre-nursing students' knowledge of antibiotic resistance and antibiotic stewardship change upon completing the I SEE-style activity (experimental group) or not completing the I SEE-style activity (control group)?

RQ3. What is the difference in students' change in understanding of antibiotic resistance between students who complete the I SEE-style activity and those who do not?

RQ4. How do students utilize the I SEE-style activity to learn about antibiotic resistance?

RQ1: Nature of Pre-Nursing Students' Understanding

I used pre-lab activity survey data to gauge the current state of pre-nursing students' understanding of key concepts relating to antibiotic resistance and stewardship. Instruction in both groups was similar before the I SEE-style activity was given, as there were no changes in curriculum and no significant changes in delivery of the information. Students' percent correctness on the pre-lab surveys is shown in Table 4. Mean score on pre-lab surveys was significantly higher in the experimental group than the control group

(t(61)=2.696; p=0.004). This difference is most evident in students' performance on questions 8, 10, and 11, all of which concern appropriate use of antibiotics (see Table 5).

Table 4. *t*-test results comparing mean pre-lab scores in the control and experimental groups.

Group	n	Mean	SD	*t*-cal	*t*-crit	df	p
Experimental	36	7.417	1.45	2.696	1.670	61	0.004
Control	34	6.5	2.561				

Table 5. Percent of students answering correctly per question on pre-lab questionnaires in control (Fall 2020) and experimental (Spring 2021) groups.

Survey Question	Control group (Fall 2020 semester)	Experimental group (Spring 2021 semester)
1. When should gloves be removed in a clinical setting?	91.4%	88.9%
2. Which of the following is as effective as cleaning one's hands with soap and running water?	68.6%	66.7%
3. Which of the following is most effective in preventing droplet transmission of disease?	79.4%	83.3%
4. Is antibiotic resistance an example of evolution?	80.0%	86.1%
5. How do mutations which can lead to antibiotic resistance happen in bacteria?	8.8%	2.8%
6. When should a patient be prescribed antibiotics?	79.4%	77.8%
7. When should a patient stop taking antibiotics that are prescribed to them?	75.8%	69.4%
8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?	40.6%	50.0%
9. Which of the following can contribute to a rise in antibiotic resistance?	75.0%	80.6%
10. Should a patient take the same antibiotic more than once?	17.6%	50.0%
11. Which of these is the only effective treatment for bacterial infection?	52.9%	77.8%

RQs 2 & 3: Ways Knowledge Changes

I used percent changes in students' scores, compared between the control and experimental groups (Table 6), to ascertain whether performance on the multiple-choice component of the RAUEQ had improved in the experimental group or not. Codes and their frequencies were compared between the two groups on free-response components of questions found to have shown a significant change between groups.

Table 6. Percent change in students answering each question correctly between control and experimental groups from pre-lab to post-lab.

Survey Question	Control group (Fall 2020 semester)	Experimental group (Spring 2021 semester)
1. When should gloves be removed in a clinical setting?	6.24%	6.19%
2. Which of the following is as effective as cleaning one's hands with soap and running water?	3.78%	16.64%
3. Which of the following is most effective in preventing droplet transmission of disease?	3.78%	-9.96%
4. Is antibiotic resistance an example of evolution?	25.00%	0.00%
5. How do mutations which can lead to antibiotic resistance happen in bacteria?	-30.68%	196.43%
6. When should a patient be prescribed antibiotics?	-8.44%	14.27%
7. When should a patient stop taking antibiotics that are prescribed to them?	15.44%	24.06%
8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?	-20.44%	22.20%
9. Which of the following can contribute to a rise in antibiotic resistance?	25.07%	17.12%
10. Should a patient take the same antibiotic more than once?	-13.64%	-44.40%
11. Which of these is the only effective treatment for bacterial infection?	53.69%	-3.59%

A *t* test was used to determine whether the percent change in correctness was significantly different between these groups, and this change was found to not be statistically significant (*t*=-1.095; p=0.139). The improvement in mean scores from pre- to post-lab questionnaire in the control group was statistically significant (*t*=-2.936; p=0.003), but not in the experimental group (*t*(61)=-1.128; p=0.133).

Table 7. *t*-test results comparing pre-lab and post-lab mean survey scores in the control group (Fall 2020).

	n	Mean	SD	*t*-cal	*t*-crit	df	p
Pre-lab	34	6.5	2.561	-2.936	1.692	33	0.003
Post-lab	34	7.265	2.019				

Table 8. *t*-test results comparing pre-lab and post-lab mean survey scores in the experimental group (Spring 2021).

	n	Mean	SD	*t*-cal	*t*-crit	df	p
Pre-lab	36	7.417	1.45	-1.128	1.689	35	0.133
Post-lab	36	7.75	2.993				

Mean post-lab RAUEQ scares were also compared between the control and experimental groups. Differences in these mean scores were not found to be statistically significant (*t*=1.286; p=0.101).

Table 9. *t*-test results comparing mean control group post-lab scores to mean experimental group post-lab scores.

	n	Mean	SD	*t*-cal	*t*-crit	df	p	Decision
Experimental	36	7.75	2.993	1.286	1.668	67	0.101	reject
Control	34	7.265	2.019					

Frequencies of themes found in RAUEQ free-response rationales were measured in order to gauge, descriptively, which themes were more or less common in post- versus pre-lab responses in both groups. These frequencies may be seen in Figures 1 and 2 below.

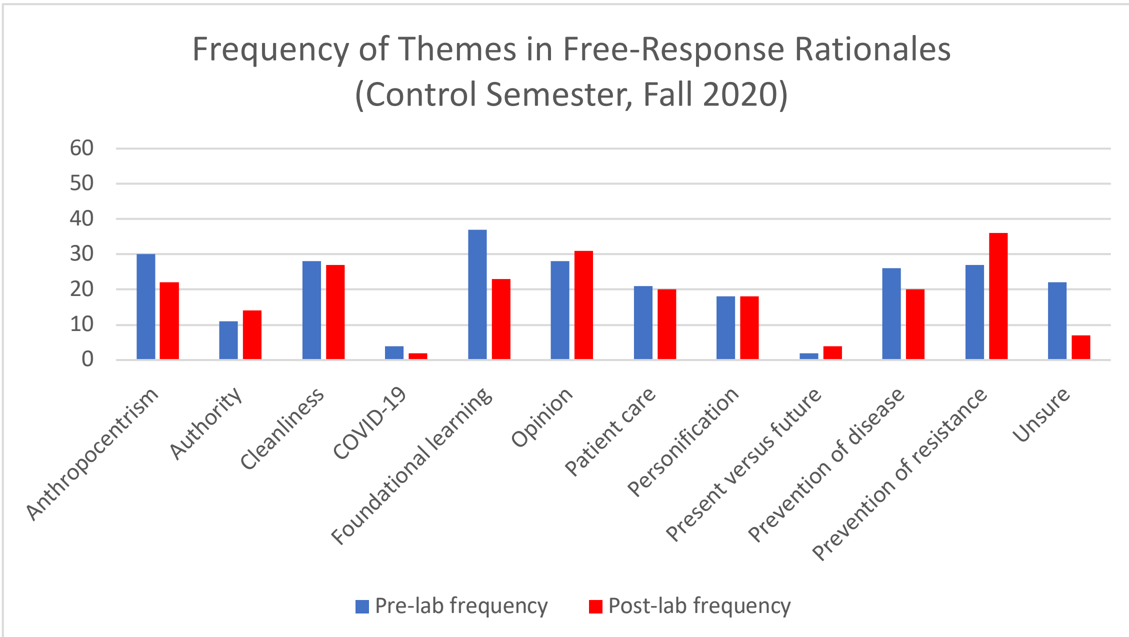

Figure 1. Frequencies of each theme in pre- and post-lab free-response rationales in the control group (Fall 2020). Frequencies are presented in number of mentions of the theme across all questions.

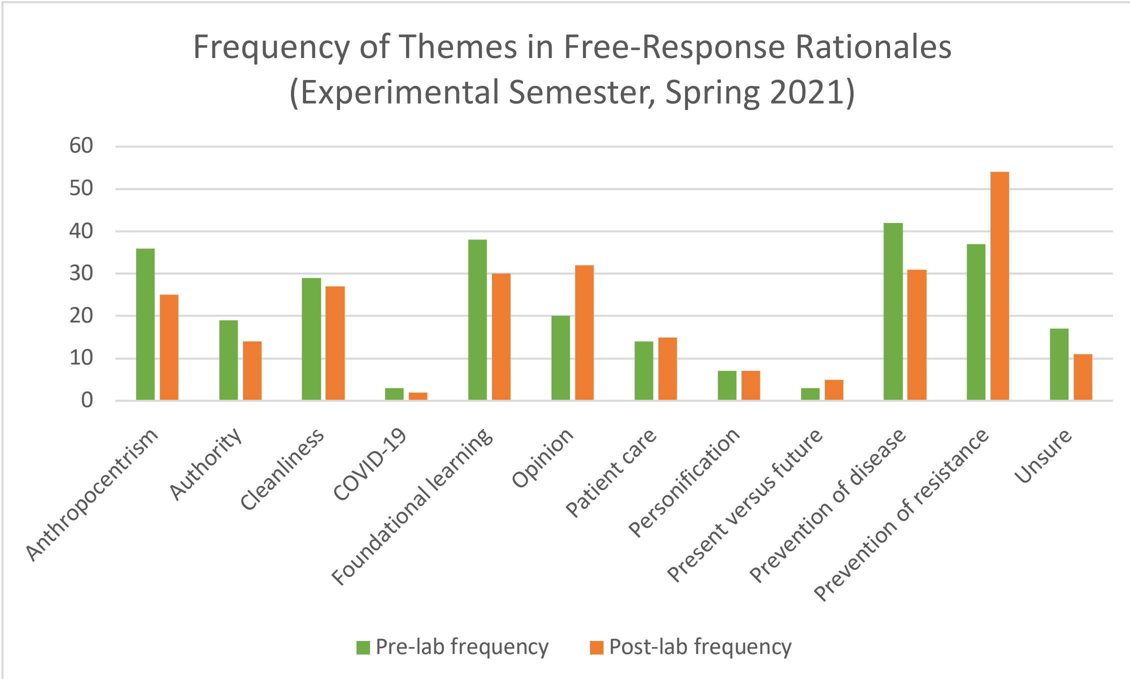

Figure 2. Frequencies of each theme in pre- and post-lab free-response rationales in the experimental group (Spring 2021). Frequencies are presented in number of mentions of the theme across all questions.

The most noteworthy differences in theme frequency in the control semester are use of the themes **foundational learning** and **unsure**. Both themes diminished in frequency between pre- and post-lab responses. In the experimental group, a marked increase is seen in **prevention of resistance** and **opinion**, while decreases are evident in the frequency of **anthropocentrism** and **prevention of disease**.

The following sections (Positive Changes: Incorrect to Correct and Negative Changes: Correct to Incorrect) over the next 24 pages detail the ways in which student rationales changed between pre- and post-lab responses to the RAUEQ. These qualitative data supplement the quantitative data already presented in answering RQs 2 and 3—evaluating how students' thinking changed before and after lab instruction.

Positive Changes: Incorrect to Correct

Rationales of individual students whose answer changes from an incorrect pre-lab answer choice to a correct post-lab answer choice were examined more closely for differences in what codes were used in explanations that might explain what affected those students' reasoning as a result of participation in the lab activity.

Question 1.

Three students in the control group changed their answers from an incorrect to a correct answer on Question 1. Of these, only one showed any change in her rationale:

> "You should only remove gloves after you are done with working with any fluids" (Beatrix, pre-lab)
>
> "All of these methods prevents spreading germs" (Beatrix, post-lab)

This student used nonspecific language that re-stated the text of the answer choice she selected before participating in the lab activity, but afterward referred to **prevention of disease** as a reason to change gloves in each situation.

In the experimental group, three students changed from an incorrect pre-lab answer choice to a correct post-lab answer choice. Two students did not noticeably change their rationales, but one student's pre-lab rationale reflected the correct answer choice despite having chosen an incorrect option:

> "Gloves must be changed when dealing with different patients for sanitary reasons. Hands should be washed prior to and after glove use. Gloves should be changed even if you don't come into contact because there is still a ubiquity of microorganisms present everywhere." (Turner, pre-lab)
>
> "Hand hygiene is critical in clinical settings." (Turner, post-lab)

It is unclear why this student selected answer choice *B.* when her rationale more closely reflected answer choice *D.*, but she corrected her error in her post-lab response.

Question 2.

In the control group, four students switched from an incorrect answer in their pre-lab responses to a correct answer in the post-lab. Of these, one student changed her rationale from **physical removal** to **thoroughness**:

> "To rub off the dead bacteria" (Bronagh, pre-lab)
>
> "To completely coat the hands and kill bacteria" (Bronagh, post-lab)

Two other students seemed to misinterpret the question as asking for a second-best choice after washing hands with soap and running water:

> "Washing hands for 20-30 seconds efficiently removes bacteria, however hand sanitizer with 70% alcohol content is used to disinfect in lab and on our hands." (Deirdre, pre-lab)
>
> "Washing hands for 20-30 seconds properly effectively cleans your hands better than hand sanitizer" (Deirdre, post-lab)
>
> "I believe that washing hands is more effective than using alcohol because washing hands can eliminate more germs. Whereas, hand sanitizer is only useful if not water and soap are around *[sic]*." (Jaelynn, pre-lab)
>
> "I believe that washing your hands is more effective because this is the most effective way to get rid of the most germs." (Jaelynn, post-lab)

Both students also referenced **thoroughness** in their post-lab rationales.

In the experimental semester, six students changed their answers to a correct post-lab response. As in the control group, four students thought the question was asking which method was the best alternative to using soap and running water:

> "In the correct setting, you could use hand sanitizer as a replacement for hand washing but should always try and wash your hands with soap and water." (Alexis, pre-lab)
>
> "Washing hands is the best method" (Alexis, post-lab)
>
> "The alcohol will kill most microbes and can be used when there is no soap and water. Using water without soap is ineffective and may even multiple *[sic]* some bacteria on your hands bc *[sic]* some bacteria like water. I am unsure about the towelette" (Tobias, pre-lab)
>
> "washing hands is most effective but the alcohol hand sanitizer is a good alternative as well." (Tobias, post-lab)
>
> "If soap and water are not available, hand sanitizer with 70% alcohol content is just as effective." (Teagan, pre-lab)
>
> "Use hand sanitizer with at least 60% alcohol is you do not have soap and water, but it is not as effective as washing your hands." (Teagan, post-lab)

Two students actually changed their rationales from believing that hand sanitizer was actually just as effective as washing with soap and water:

> "70% alcohol content sanitizer is as effective" (Eunice, pre-lab)
>
> "While hand sanitizer is effective nothing is as effective as washing your hands for 60 seconds with soap and water" (Eunice, post-lab)
>
> "This is the safest amount of alcohol content to use and is the most effective in limiting the amount of transmission of germs." (Ava, pre-lab)
>
> "The most effective way is cleaning your hands properly with soap and water for at least 20 seconds if not more" (Ava, post-lab)

Question 3.

In the control group, four students changed their answers from incorrect in their pre-lab responses to correct in their post-lab responses. Two of these students changed their answers from *B.* to *C.* with the understanding that covering one's cough with one's arm leaves **contaminants** on the arm that could be spread elsewhere:

> "All of thx s *[sic]* are good answers but to prevent the spread of droplets is to cover your couch *[sic]* so those droplet particles don't go and land on other surfaces causing other individuals to touch the droplets and catching the sickness" (Olivia, pre-lab)
>
> "This is what they are making us do during covid *[sic]* to prevent the cough particles from getting in contact with another person" (Olivia, post-lab)
>
> "Covering coughs and sneezes with your elbow reduces the risk of droplets going into the air. This ensure *[sic]* no one around you breathes in the particles you just sneezed/coughed out." (Dhaani, pre-lab)
>
> "This is the best way to ensure that all bacteria that you are spitting out stays on you and not other people. Plastic face shields still allow for bacteria particles *[sic]* to get into the air, and covering a sneeze with your hand transfers the bacteria to your hand and to surfaces you touch if you dont *[sic]* wash your hands immediately after." (Dhaani, post-lab)

One student only changed her answer to the multiple-choice item, and retained her wrong answer in her rationale:

> "This [the face shield] covers entire face *[sic]* so any droplet exposed to individual will be blocked out by shield" (Bedelia, pre-lab)

> "If you have a face shield and someone were to sneeze on your face – the shield would cover your *[sic]* and non of the *[sic]* droplets, that may potentially have infectious microbes, will not *[sic]* get in contact with you." (Bedelia, pre-lab)

One student apparently learned more about the distance which respiratory droplets could travel:

> "I think keeping distance would be the most effective because you are far away from the droplets" (Alisa, pre-lab)
>
> "To prevent from *[sic]* droplets traveling elsewhere" (Alisa, post-lab)

In the experimental group, two students changed their answers to a correct post-lab response. One student first focused on the porosity of the material, then on the distance from the mouth and nose:

> "The droplets wouldn't be able to penetrate the plastic face shield. Droplets may still be able to get through the masks depending on the material they're made of. Social distancing doesn't stop droplets from getting in the air, it just makes it harder for them to reach other people. Coughing into your elbow doesn't directly get rid of droplets since some will still get in the air, and it also contaminates the clothing which could in turn spread it." (Sínead, pre-lab)
>
> "The mask is directly in front of your mouth and nose and there's little chance of particles going elsewhere." (Sínead, post-lab)

The other student changed her priority from social distancing to wearing a mask that covers the mouth and nose, though continued to recommend using both simultaneously for best results:

> "Microbes can only travel 1 meter or 3 feet when exhaled so by maintaining at least 4 preferably 6 plus feet between others limits the chance of you coming into contact

with there *[sic]* droplets. Masks are helpful and would be my second choice but since viruses are so small they can still fit through the mask so if you are standing close to a person and you both are wearing mask you could still get sick. Preferably I would do both and wear a disposable mask with a reusable mask over it for extra protection or even doing all of the above." (Ava, pre-lab)

"I would say this answer along with the 6 feet distance but the mask helps prevent droplets from getting far and the 6 feet ensures that even if they do get through the mask that they will not reach you." (Ava, post-lab)

Question 4.

In the control group, six students answered incorrectly in their pre-lab responses, then correctly in the post-lab. Five of these students changed their responses from *C.* to *A.*, thereby moving from an **unsure** rationale to another rationale. These post-lab rationales differed, with one student simply referencing **mutation**:

"Gene mutation" (Olivia, post-lab)

Another **personified** bacteria to explain the development of resistance to antibiotics:

"Antibiotic resistance *[sic]* bacteria learns from antibiotics and changes based on those antibiotics so that they can be stronger and live longer." (Ariana, post-lab)

Another equated evolution to any **change over time**:

"Antibiotic resistance changes over time." (Maxine, post-lab)

The last referenced the misconception that the human body is what develops resistance to antibiotics:

"I would say yes because our bodies have evolved to be resistant to certain antibiotics." (Dorothy, post-lab)

The student who changed her response from *B.* to *C.* used an **anthropocentric** rationale for her incorrect answer, then changed her post-lab rationale to an **unsure** statement about **heritability**:

> "I don't think it is because we have created these crazy strong viruses by not completing our medication so now they are resistant to the medicine." (Erica, pre-lab)
>
> "I think it can be passed genetically….?.? *[sic]*" (Erica, post-lab)

In the experimental group, three students changed from an incorrect pre-lab to a correct post-lab answer. One student changed from *B.* to *A.* and two changed from *C.,* to *A.* Those changing from *C.* to *A.* changed rationales from **unsure** responses, with one instead referencing **natural selection**:

> "Antibiotic resistant is a example *[sic]* of evolution because of natural selection." (Shanice, post-lab)

The other student took a more **anthropocentric** approach:

> "Antibiotic resistance has changed since antibiotics were first invented, and will continue to change until there is a solution." (Annunziata, post-lab)

The student who changed her answer from *B.* to *A.* used a misconception that the **body is resistant** in both her pre- and post-lab rationales:

> "Is not apart *[sic]* of evolution because more people of everyone would be resistant to antibiotics but not everyone is" (Tawny, pre-lab)
>
> "I think it is an example of evolution because as years go on many people become resistant because of their parents or family" (Tawny, post-lab)

Question 5.

In the control semester, only one student changed her answer from an incorrect response to a correct response after the lab activity. This student used an anthropocentric approach in her pre-lab rationale, in which she analogized bacterial evolution to a human immune response. In her post-lab rationale, she appeared to have learned the difference between *causes* of mutation and what can *perpetuate* mutations in a population:

> "Just like how we gain antibodies from being exposed to bacteria, they can build up resistance to antibodies *[sic]*. Mutations are a random occurrence. Maybe cells are able to communicate about antibodies *[sic]*." (Aoife, pre-lab)
>
> "Mutations are always a result of random chance. Quorum sensing or seeing an antibiotic too much would build up resistance but would not be a result from a mutation." (Aoife, post-lab)

In the experimental semester, two students went from incorrect pre-lab responses to correct post-lab responses. Both students mentioned **heritability** in their pre-lab rationales, but, as in the control semester, appeared to differentiate between causation of mutations and selective pressure for those mutations:

> "These are different ways the bacteria pass on the genes that survive the antibiotic." (Tobias, pre-lab)
>
> "Mutation is random." (Tobias, post-lab)

The other student's pre- and post-lab rationales were almost identical to the student's above.

Question 6.

In the control group, three students changed their responses to be correct after the lab activity. Two of these moved from a **better safe than sorry** approach in their pre-lab rationales to an approach more focused on **patient care** in their post-lab rationales:

"When someone comes in contact with someone who has a virus's *[sic]* or infection, they have a percentage of getting whatever they came in contact with. When someone does have a virus or bacteria infection *[sic]*, medicine can cure except covid-19 *[sic]*." (Olivia, pre-lab)

"You shouldn't give medicine to someone who may be expose *[sic]* because without knowing for sure and giving medicine without an infection is pointless and can do harm" (Olivia, post-lab)

"Antibiotics should be prescribed in all these scenarios because it'll stop the infections caused by bacteria no matter what degree of the infection." (Dorothy, pre-lab)

"A patient should be prescribed antibiotics when they are actually diagnosed with a bacterial infection to prevent having to take an antibiotic for no reason." (Dorothy, post-lab)

The third student shifted her focus from **preventing disease** to **preventing resistance**:

"So that bacteria will not be able to spread" (Ariana, pre-lab)

"They should only take antibiotics when they are told to by their doctor when they are diagnosed so that the bacteria inside of them doesn't get used to the antibiotic. If the bacteria gets used to it, then if they were to actually get that disease, the antibiotic would not work." (Ariana, post-lab)

In the experimental group, seven students changed their answers from an incorrect to a correct response after participating in the lab activity. Five of these students shifted their rationales to **preventing resistance** after the lab activity:

"any antibiotics can prevent, treat and help with bacterial infections." (Sonja, pre-lab) "only when infected is best to keep the patient from over exposure to antibiotics" (Sonja, post-lab)

"If the patient is in enough pain or discomfort before a true diagnosis they should be prescribe *[sic]* antibiotics to help treat there *[sic]* potential infection" (Eunice, pre-lab)

"After proper diagnosis of the infection can be concluded to prevent the further antibiotic resistant bacteria from appearing due to random exposure of antibiotics" (Eunice, post-lab)

One student changed her priority from speed of care to quality of care:

"I picked this because it's important to kill the bacteria fast so it will do less harm to the host." (Shanice, pre-lab)

"If you take antibiotics and there is nothing foe *[sic]* it to treat it could effect you *[sic]* and these antibiotics should be taken when the person is official *[sic]* diagnosed so the wrong antibiotic is not given" (Shanice, post-lab)

Another student, who emphasized patient compliance in her pre-lab rationale, appeared to notice the answer choices mentioning viral infections in her post-lab rationale:

"it is never bad to be prescribed antibiotics, BUT once prescribed, the dose must be finished to ensure it works fully." (Stephanie, pre-lab)

"antibiotics don't treat viral infections." (Stephanie, post-lab)

Question 7.

In the control group, four students responded correctly after the lab activity, having answered incorrectly before. Three students' rationales did not change—one remained unsure of her answer, and the other used almost the exact same rationale. One student went from being unsure to referring to a doctor's **authority** and taking measures to **prevent resistance**:

"I don't really know for sure. But they all seem right." (Ariana, pre-lab)

"They should stop taking them when the prescription runs out because they are given a certain amount for a reason and if they don't follow that, the antibiotic may not work correctly or the bacteria could develop a resistance." (Ariana, post-lab)

In the experimental group, four students changed incorrect pre-lab answers to correct answers after the lab activity. Two students referred to a doctor's **authority** in both their pre- and post-lab rationales:

"Always consult your medical provider about how long you should take them for." (Turner, pre-lab)

"The doctor is the only person who should decide the length of treatment." (Turner, post-lab)

One student explicitly said in her post-lab rationale that the lab activity had taught her about changing antibiotic use patterns to **prevent resistance**:

"All of them are valid answers since the prescribed *[sic]* would most likely have an timeframe *[sic]* of when they shouldn't need antibiotics anymore. If the patient feels better, it's not the best answer but if they don't feel worse after a while, then it should be fine. And if the person starts feeling worse after taking the antibiotics, I would say talk to their doctor but stopping for the time being would be good." (Tess, pre-lab)

"I now know that antibiotic resistance is a problem that is continually growing. So finishing the antibiotic course prescribed or when the doctor says that they can stop would be best." (Tess, post-lab)

One student mentioned **preventing infection** in her post-lab rationale:

"If their prescription runs out it means that they have completed their antibiotics, if the patient is feeling better then the prescription can be discontinued. If the patients *[sic]* symptoms are worse they should stop and go to their healthcare provider." (Skye, pre-lab)

"To make sure that the infection is treated" (Skye, post-lab)

Question 8.

In the control group, three students changed their incorrect pre-lab responses to correct post-lab responses. Two of these students' rationales remained the same. The other changed her focus from the **speed** at which the infection could be treated to the quality of **patient care**:

"It is better to start fighting the pathogen early on." (Maxine, pre-lab)

"It is best if we wait to prescribe antibiotcs, *[sic]* because we should limit the amount of antibiotic prescriptions a patient is on." (Maxine, post-lab)

In the experimental group, nine students corrected their answer in their post-lab responses. One did not change her rationales. Five of these mentioned **preventing resistance** in their post-lab rationales:

"It is best to immediately try to use antibiotics to knock out the bacterial infection." (Teagan, pre-lab)

"The prescriber needs to be sure that they know the cause before starting an antibiotic, because if a patient takes an antibiotic they do not need they might develop resistance in the future." (Teagan, post-lab)

"While waiting to know exact cause *[sic]* would be helpful it can be better in some cases to give immediate treatment as to help with an pain *[sic]* or discomfort that the patient is experiencing." (Eunice, pre-lab)

> "Waiting to prescribe an antibiotic will help slow the antibiotic resistant bacteria from appearing" (Eunice, post-lab)

Three focused on **best practices** in prescribing antibiotics in their post-lab rationales:

> "It truly depends on the provider. For example, if you go to an ER and explain broad symptoms, they will prescribe you broad-spectrum antibiotics that *might* help your infection. If you go to your primary care physician, they may take more time to do certain testing to determine what exactly may be causing your illness and prescribe the correct course of action such as narrow-spectrum antibiotics." (Beulah, pre-lab)

> "The ideal course of action would be finding out whether the infection is Gram-positive or Gam-negative in order to prescribe the right course of antibiotics, although unfortunately this usually does not happen." (Beulah, post-lab)

Question 9.

In the control group, four students changed their responses from an incorrect pre-lab response to a correct response after the lab activity. All of these students primarily blamed overuse by humans in their pre-lab rationales, changing to a less specific pot-lab rationale essentially stating that they agreed with all of the responses.

In the experimental group, six students changed their answers from incorrect to correct responses. All of these students also referenced anthropocentric views on the causes of antibiotic resistance in their pre-lab rationales; however, only one explicitly cast off this view in her post-lab response:

> "Inappropriate prescribing can lead to more survivor bacteria from many other antibiotics." (Theodora, pre-lab)

"All of these options allows *[sic]* some bacteria to survive these condition *[sic]* and pass on these genes." (Theodora, post-lab)

One student mentioned the lab activity by name in her post-lab rationale:

"Bacteria can become immune to antibiotics." (Valeria, pre-lab)

"I learned this during our I SEE presentations." (Valeria, post-lab)

Question 10.

In the control group, two students changed their responses from a pre-lab incorrect response to a post-lab correct response. One of these students did not substantively change her rationale, but the other changed her rationale from an observation based on her own **personal experience** to a reference to **patient compliance** with prescribers' orders:

"The amount of time *[sic]* I have gotten flu or strep, I still take the same antibiotic to make me feel better. So it's okay to take the same antibiotic but only if your body needs it" (Olivia, pre-lab)

"Yes if they take it in the correct moderation." (Olivia, post-lab)

In the experimental group, four students changed their responses to a correct answer after the lab activity. Of these, two students did not change their rationales. One changed from a focus on **preventing resistance** to an admission that she was unsure of her rationale behind her response:

"The same antibiotic used multiple times allows the disease to be exposed and become resistant to it" (Sloane, pre-lab)

"Unsure" (Sloane, post-lab)

One student stated that a time delay was necessary between prescriptions in her pre-lab rationale, but her post-lab rationale was significantly less clear:

"i *[sic]* think it is okay as long as it isn't right after the first use" (Tamzin, pre-lab) “only prescribed should take *[sic]*” (Tamzin, post-lab)

Question 11.

In the control group, ten students changed from an incorrect pre-lab answer to a correct post-lab answer. Of these, eight offered vague re-statements of the answer choice in their rationales or did not substantively change their rationale from pre-lab to post-lab. The others compared **present versus future** treatments available:

“Antibiotics tend to work in bacteria.” (Alisa, pre-lab)

“New ways to treat bacterial infections are being created” (Alisa, post-lab)

“antibiotic treatment is the only know *[sic]* proven successful method” (Danica, pre-lab)

“Since antibiotic resistance is rising, new methods are being used to treat infections” (Danica, post-lab)

In the experimental group, five students changed their answers from incorrect before lab to correct afterward. Three of these students focused on differences between **present versus future** treatments for bacterial infection:

“As time progresses, bacteria are becoming more resistant so I would not consider antibiotics as the most effective way to treat a bacterial infection. Treating the symptoms would be temporary but if the bacteria is not treated the symptoms could come back. Therefore, I think new science *[sic]* of using phage therapy and quorum sensing inhibitors could prevent the grouping and communication of bacteria I *[sic]*. If they cannot group then they can’t attack.” (Tiffany, pre-lab)

“Antibiotics is slightly effective right now, but as we use them more it’s becoming ineffective because of antibiotic resistance. There are new treatments that are starting to occur that involve gene therapy which tries to stop communication between bacteria. This would be effective because if they cannot communicate then they cannot launch a bacterial attack." (Tiffany, post-lab)

Others simply offered vague expressions of agreement with the answer choice in their post-lab rationales.

Negative Changes: Correct to Incorrect

Rationales of individual students whose answer changes from a correct pre-lab answer choice to an incorrect post-lab answer choice were also examined more closely for differences in what codes were used in explanations that might explain what affected those students' reasoning as a result of participation in the lab activity.

Question 1.

In the control group, only one student changed her answer from the correct response to an incorrect response. This student gave a similar post-lab rationale to her pre-lab rationale, with both focusing on **contamination**, but was less specific in applying this rationale:

> "You need to change your gloves when you come in contact with any bodily fluids because your gloves are now further contaminated with a individual's *[sic]* fluids. Second, you need to change your gloves when you come in contact with different patients because you don't want to spread whatever Patient A had to Patient B. Third, gloves need to be changed when hands are washed because it is counterproductive to wash your hands then proceed to put on contaminated gloves" (Dorothy, pre-lab)
>
> "this should occur because we want to prevent cross contamination" (Dorothy, post-lab)

In the experimental group, one student changed her answer from a correct pre-lab to an incorrect post-lab response. This student showed a similar change in rationale to the student in the control semester described above—she gave a thorough pre-lab rationale focusing on **contamination**, but gave a far less detailed post-lab rationale:

> "One should remove gloves after coming into contact with any bodily fluids as it can transfer onto other surfaces that you may touch. Gloves should be removed every time after coming into contact with a patient and new gloves should be used for the next patient. When hands need to be washed the gloves should be removed for effective handwashing." (Skyre, pre-lab)
>
> "To reduce secondary infections due to reduce *[sic]* transmission of bacteria from bodily fluids" (Skye, post-lab)

Question 2.

In the control group, three students changed their answers from correct pre-lab responses to incorrect post-lab responses. All of these students appeared to misunderstand what the question was asking, and instead of giving an answer regarding which method was *as* effective as washing with soap and water, instead answered with which method they felt was *second best* to using soap and water. Each rationale was similar:

> "Washing hands with soap and water is the best method." (Maxine, pre-lab)
>
> "70% alcohol is the closest technique to washing your hands." (Maxine, post-lab)

In the experimental group, two students changed from correct answers before the lab activity to incorrect answers afterward. Both appeared to have similar misunderstandings as did the students described in the control group above:

> "usually, hand sanitizer would be a response but even then it isn't as good as soap and water" (Julianna, pre-lab)

> "in order to kill some of the bacteria that is unwanted it should be at least 70%" (Julianna, post-lab)

Question 3.

In the control group, two students answered correctly in their pre-lab responses, but answered incorrectly after the lab activity. One student did not give a substantively different rationale, but the other focused on **contamination** of face masks:

> "Other than wearing a mask, the other options have the ability to pass germs directly or indirectly to other people." (Crystal, pre-lab)
>
> "Keeping a safe distance is better than the other options because the other options will be contaminated and carried to other places." (Crystal, post-lab)

In the experimental group, five students changed correct pre-lab answers to incorrect post-lab answers. Students who changed their answers from masks to face shields focused on their impermeability:

> "It covers the germs." (Samiya, pre-lab)
>
> "The face sheild *[sic]* is actaully *[sic]* plastic so it may prevent germs from actually coming to your face. A cloth mask may be helpful but not the most effective." (Samiya, post-lab)

The student who instead selected covering one's cough with the hand or elbow did not substantively change her rationale post-lab, choosing to focus on containment of droplets:

> "I would say wearing a disposable or washable mask covering the nose and mouth would be the most effective because this ensures droplets do not leave or enter the mask, preventing droplets from reaching others or other surfaces." (Artazia, pre-lab)

"Covering a cough greatly decreases the chance of transmission of droplets due to preventing these droplets from contaminating the air as best as possible." (Artazia, post-lab)

Students who changed their answers from masks to keeping distance assumed that three feet was enough to allow droplets to leave the air:

"That's what everyone wears in the pandemic" (Shareen, pre-lab)

"Droplets only Travel *[sic]* that far" (Shareen, post-lab)

Question 4.

No students answered this question incorrectly in the control semester after the lab activity, regardless of their responses in the pre-lab questionnaire.

In the experimental semester, three students changed correct pre-lab responses to incorrect post-lab responses, and all of these students expressed being **unsure** in their post-lab rationales:

"Because it causes more infections." (Samiya, pre-lab)

"I really don't know. If I did I would give my best honest answer." (Samiya, post-lab)

Question 5.

In the control group, two students changed their answers from correct pre-lab responses to incorrect post-lab responses. One student did not give rationales to either of her answers, and the other expressed being **unsure** before and after the lab activity:

"I don't really know, but I know that when we talked about biofilms we never talked about mutations within them so I think that one is wrong." (Erica, pre-lab)

"I think. I know it's not biofilms because biofilms can grow anywhere, not just in the presence of antibiotics." (Erica, post-lab)

No students in the experimental group who answered correctly in the pre-lab questionnaire answered incorrectly in the post-lab questionnaire.

Question 6.

In the control group, five students changed their correct pre-lab answers to incorrect answers after the lab activity. Three of these focused on antibiotics not working against **viral** infections:

> "Viruses don't die with antibiotics" (Bronagh, pre-lab)
>
> "Don't give as precaution bc *[sic]* we need to limit about *[sic]* of antibiotics given. Given with viral infections to treat symptoms but antibiotics have no affect *[sic]* on viruses" (Bronagh, post-lab)

The other two focused on **preventing resistance**:

> "Using antibiotics as scarcely as possible prevents antibiotic resistance" (Bethann, pre-lab)
>
> "Limit prescription of bacteria" (Bethann, post-lab)

In the experimental group, three students changed their answers from correct in the pre-lab questionnaire to incorrect in the post-lab questionnaire. Two focused on treating infection as **rapidly** as possible:

> "Antibiotics are only effective towards bacterial infections." (Lisbet, pre-lab)
>
> "Before symptoms occur is a good time to start antibiotics to lessen the symptoms and fight the bacterial infection efficiently" (Lisbet, post-lab)

The third concentrated on **preventing resistance**:

> "Because it's an antibiotic, it can be effective against bacteria." (Tess, pre-lab)
>
> "I would say all of these, but only when truly necessary so as to speed up *[sic]* the antibiotic resistance problem" (Tess, post-lab)

Question 7.

No students in the control group who answered correctly before the lab activity answered incorrectly afterward.

In the experimental semester, one student who answered incorrectly after the lab activity answered correctly in the pre-lab questionnaire. Her rationale did not change, only her multiple-choice response.

Question 8.

In the control group, six students answered correctly before lab, then incorrectly afterward. Five of these changed their answer to *C.*, which was an all of the above option, and their rationales did not change significantly. The sixth, however, changed her priority from **patient care** to **trial and error** to aid in the diagnostic process:

> "I feel like narrowing it done *[sic]* more allows for a better treatment plan for the patient." (Purbita, pre-lab)
>
> "begin with a broad spectrum antibiotic to see if it helps and if not then try to find something more specific" (Purbita, post-lab)

In the experimental group, five students answered correctly in the pre-lab questionnaire, then incorrectly in the post-lab. Four of these changed their answer to *C.*, and most of them did not change their rationales. One of these students, however, changed her focus from **preventing resistance** in her pre-lab rationale to an expression of being **unsure** with an anecdote about her own **personal experience** in her post-lab rationale:

> "giving antibiotics to people if they don't have any infection is the reason why there is antibiotics resistance *[sic]* now, you should only be prescribed it the *[sic]* infection is there" (Julianna, pre-lab)

"it is hard to tell personally I have had both options done to me when I am sick" (Julianna, post-lab)

The student who changed his answer to *B.* shifted his focus from quality of **patient care** to the **speed** of resolving the infection:

> "Certain antibiotics will do certain things in the body and affect different areas, so it's better to wait until you find out what exactly is going on in order to start a narrow spectrum treatment." (Laurence, pre-lab)
>
> "Immediately starting antibiotics will reduce the patient's symptoms until the doctor is able to figure out exactly what is wrong/what bacteria is infecting the patient." (Laurence, post-lab)

Question 9.

None of the students in the control group who selected a correct answer in the pre-lab questionnaire changed their response to be incorrect in the post-lab questionnaire.

Only one student in the experimental group changed his answer from a correct to an incorrect response. In his post-lab rationale, he used the same approach, **personifying** the bacteria, but instead focused on a more anthropocentric view, blaming antibiotic misuse and overuse for resistance:

> "Antibiotic resistance is emerging from all of the following due to the fact that wastewater and livestock contain multiple types of bacteria who learn to fight against antibiotics. Additionally, inappropriate prescriptions will allow bacteria to grow since they're not stopped from the medicine you SHOULD be taking." (Laurence, pre-lab)
>
> "The more antibiotics are used, the more resistant the bacteria can become because sensitive bacteria are killed, but stronger germs resist the treatment and grow and multiply." (Laurence, post-lab)

Question 10.

In the control group, three students who answered correctly before lab answered incorrectly afterward. One student's rationales did not change significantly between her pre- and post-lab responses. The other two students took a more over-cautious approach, citing **preventing resistance** in their post-lab rationales:

> "Certain antibiotics are used to treat specific infections. For example, if you get strep, typically the same antibiotics are given." (Deirdre, pre-lab)
>
> "A patient can take an antibiotic more than once as long as the bacteria has not built up a resistance to the antibiotic" (Deirdre, post-lab)

In the experimental group, 12 students answered correctly in their pre-lab questionnaire and incorrectly post-lab. Of these, eight students did not change their rationales significantly. Two students cited over-caution against antibiotic **resistance**:

> "Some antibiotics can be used against various microbes and therefore it is believed to be the best method of treatment the antibiotic should be prescribed." (Selena, pre-lab)
>
> "Im *[sic]* not completely sure but If *[sic]* the antibiotic worked once it could work again. Although there is a chance that the bacteria have developed resistance ot that antibiotic." (Selena, post-lab)

One mentioned precaution about the **body developing resistance** to the drug:

> "You can and should take the antibiotics every time you get the infection. There may be stronger side effects." (Tanji, pre-lab)
>
> "I don't think so because the body should be used to it the first time." (Tanji, post-lab)

Another mentioned that **side effects** may be stronger upon subsequent uses of the same antibiotic:

> "Antibiotics will continue to work more than once, they are unlike that of viruses. (If you get a virus, your vaccine will protect you for a given amount of time.)" (Laurence, pre-lab)
>
> "There's an increased risk of side effects if you take 2 doses closer together than recommended. Accidentally taking 1 extra dose of your antibiotic is unlikely to cause you any serious harm. But it will increase your chances of getting side effects, such as pain in your stomach, diarrhoea *[sic]*, and feeling or being sick." (Laurence, post-lab)

One student changed her approach from presenting personal experience to one saying that the answer **depends** on other circumstances:

> "I chose this answer because I have had a couple UTI's *[sic]*, antibiotics are always prescribed and always get rid of the infection." (Annunziata, pre-lab)
>
> "It depends on the time span between the first and second infection. If there was no harm to the patient it should be fine to take the antibiotic again. I believe all answers could be correct depending on the patient and their history." (Annunziata)

One student apparently used a correct rationale for her incorrect post-lab answer.

Question 11.

In the control semester, two students changed their correct pre-lab answers to incorrect post-lab answers. One appeared to guess on her pre-lab response, as she simply stated "I don't know" in her pre-lab rationale. The other talked about a stronger preference for antibiotics in her post-lab response:

"All of these can be effective towards treating a bacterial infection. Antibiotics can help, medication could, and quorum sensing inhibitors can by preventing communication between the bacteria." (Deirdre, pre-lab)

"Antibiotics are the most effective way to kill a bacterial infection" (Deirdre, post-lab)

In the experimental semester, six students changed correct pre-lab answers to incorrect post-lab responses. All six of these students showed higher trust in antibiotics, generally because they are more well-established:

"many treatments can be used to treat bacterial infection" (Sonja, pre-lab)

"antibiotics have had better testing and research to find the best possible way of getting rid of bacterial infections" (Sonja, post-lab)

"All of these are correct because there are multiple ways to treat a bacterial infection" (Shanice, pre-lab)

"Antibiotics are the main thing that can help bacterial infections" (Shanice, post-lab)

RQ4. How Students Used the I SEE-Style Activity

In order to answer this question, we analyzed students' responses to the post-lab evaluation questions. Students' responses to the Likert-style questions about their satisfaction with the lab activity in the experimental group (Kirby-Bauer assay and I SEE-style activity) were compared to responses from the control group (Kirby-Bauer assay) about their satisfaction and tested for differences. I hypothesized that students would be significantly more satisfied with all aspects of the I SEE-style activity. We also examined trends in the qualitative responses to relevant questions in the experimental group only, as that is the group that used the I SEE-style activity.

Student Satisfaction

Table 10 shows students' overall experiences of the lab activity in each semester.

Table 10. Students' responses to the question "How would you rate your overall experience of this lab activity?"

Response	Control group (Fall 2020)	Experimental group (Spring 2021)
Not valuable or helpful	6.89% (2 of 29)	5.56% (2 of 36)
Helpful, but not with course material	6.89% (2 of 29)	11.11% (4 of 36)
Interesting, but not helpful	10.34% (3 of 29)	11.11% (4 of 36)
Interesting and helped me engage with course material	75.86% (22 of 29)	72.22% (26 of 36)

Table 11 shows students' satisfaction with learning how to articulate and present a strategy to solve a problem.

Table 11. Students' responses to the question "Do you feel this lab activity helped you to better articulate and present a strategy to solve a problem?"

Response	Control group (Fall 2020)	Experimental group (Spring 2021)
Not at all	0.00% (0 of 30)	0.00% (0 of 36)
Still uncomfortable	6.67% (2 of 30)	0.00% (0 of 36)
A little more comfortable	80.00% (24 of 30)	72.22% (26 of 36)
Significantly more comfortable	13.33% (4 of 30)	27.78% (10 of 36)

Table 12 shows the extent to which students felt the lab activity would help them in their future career in nursing.

Table 12. Students' responses to the question "To what extent do you think your experience with this lab activity will help you in your future career?"

Response	Control group (Fall 2020)	Experimental group (Spring 2021)
Not helpful	6.67% (2 of 30)	0.00% (0 of 36)
Somewhat helpful	13.33% (4 of 30)	22.22% (8 of 36)
Makes me better equipped	33.33% (10 of 30)	47.22% (17 of 36)
Gives critical skills	46.67% (14 of 30)	30.56% (11 of 36)

No clearly defined trends stand out from these data. While there are a few more students that rate themselves more comfortable with presenting a strategy to solve a problem in the experimental semester than the control semester, that is to be expected, as only the experimental group participated in a lab activity involving problem solving. Students felt similarly about both activities despite their differences, and both groups felt similarly prepared for their future careers.

Student Perceptions of the I SEE-Style Activity

Dissatisfaction with the activity largely centered around negative perceptions of group work, especially in the light of modifications made to course modality to accommodate the COVID-19 pandemic:

> "I hate group presentations. I always end up doing all of the work and we learned nothing. it was truly TRULY *[sic]* a waste of everyone's time. we simply made up a random plan and then read of the slides…? *[sic]*" (Suzanne)
>
> "it was really hard to complete within an online setting" (Skye)

Students also felt confused about what answers were "right" or "wrong", or felt the scenario planning was too hypothetical to be useful:

> I felt the group project was sort of "busy work". The instructions for the project were not very specific on how to gather material and explain a plan. My group and the other group in my lab had to different *[sic]* approaches and I am still unsure if either of us completed the project correctly due to the lack of instruction." (Annunziata)
>
> "It was very hypothetical but it would be nice to actually implement this stuff but ya know. *[sic]*" (Tobias)

Those who thought the project was interesting but not helpful either thought it was too much information or too similar to the information they had already learned:

> "i *[sic]* liked hearing all of the information, but i *[sic]* personally didn't retain everything." (Stephanie)

"I understood most of the information from lecture and the reading so the presentation was not needed. All the group presentations had about the same solutions." (Theodora)

Even students who had positive perceptions of the I SEE-style lab activity still expressed frustrations with group work and online learning:

"Group projects over zoom are not the best" (Alexis)

"The group part of the presentation wasn't that fun, but learning about it and formulating ways to slow down the emergence of antibiotic resistance was interesting." (Sínead)

Many students who enjoyed the project ascribed this enjoyment to their exposure to different perspectives and opinions from their peers:

"I enjoyed hearing different perspectives and being able to put all our minds together. We all came up with different ideas so it was good." (Tiffany)

"This project forced you to communicate with others which we will have to do in the medical field and it forced everyone to be creative and come up with ideas, rather than reciting ideas." (Selena)

Others liked the amount of independent research they had to do to supplement their understanding of resistance:

"The group presentation activity had me research and read more into antibiotic resistance in order to come up with ideas for the presentation which helped me learn even more interesting material and gave me a chance to conduct my own presentation which allowed me to engage with the material." (Beulah)

When asked if they felt the activity helped them to present problem-solving strategies, none of the students in the experimental group said they were still uncomfortable with problem-solving. Students who said they were "a little more comfortable" still showed anxiety about their level of knowledge:

> "I feel more comfortable understanding antibiotic resistance, but I would be scared to still say something that was not accurate." (Teagan)
>
> "I understand quorum sensing but there's still other factors within the conflict *[sic]* of antibiotic resistance that I am unsure about." (Laurence)

Some students appreciated how the activity showed them problem-solving processes:

> "I am more comfortable because I understand the process of solving a problem better now." (Tanji)
>
> "The project about how to solve or minimize antibiotic resistance in future years defiantly *[sic]* help me articulate and critically think of a plan of action. In many classes students are not encouraged to think critically and be creative but this lab defiantly *[sic]* helped with that.

Again, students who expressed significantly more comfort with problem-solving cited independent research as a major contributor:

> "I was able to conduct my own research and better understand the idea of bacteria resistance *[sic]*" (Tanis)

When asked whether they believed the I SEE-style activity would help them with any aspects of their future careers, many seemed to think that, as nurses, they would have no opportunity to engage in antibiotic stewardship:

> "It will definitely be important to my job as I plan to become a nurse, but I will not be prescribing the medication. This project has definitely made me more aware of the problem as a whole and I will keep it in mind when working; however, I don't

think I would be able to use this information as much as others such as doctors, researchers, etc." (Tess)

However, a few identified the patient education aspect of stewardship as one of their future responsibilities:

> "I am going for nursing, therefore, I will not be the one prescribing medication. However, now that I have an understanding I know to ask patients if they took their previously prescribed medication correctly. " (Annunziata)
>
> "its *[sic]* going to help me understand the best medical advice and help to patients know the importance of finishing prescriptions." (Sonja)

Others appreciated the creative aspects of the activity:

> "It helped me think outside the box." (Samiya)

As well as the aspects promoting collaboration and communication:

> "it improved my communication skills along with working in a group." (Valeria)
>
> "As someone pursuing nursing, knowing how to articulate a plan to problem solve will help me greatly in the field, as well as working with other individuals." (Artazia)

Full Qualitative Analysis

The following 30 pages include a full justification and count of all descriptive codes found in the qualitative data.

RAUEQ Free Response Section

After each RAUEQ multiple choice item, students were asked to justify their answer choice as a free response. Student answers were first descriptively coded, then pattern coded. Table 13 shows a brief summary of the most common codes (those with five or more occurrences) for each question before and after the lab activity. Complete definitions and rationales for each code may be found in Appendix F: Codebooks.

Table 13. Pre- and post-lab most commonly found codes in free-response rationales to each question on the RAUEQ.

Question	Fall 2020 (control semester) most common codes (≥5)	Spring 2021 (experimental semester) most common codes (≥5)
1. When should one remove gloves in a clinical setting?	a. contamination b. precaution against disease	a. contamination b. precaution against disease
2. Which of the following is as effective as cleaning one's hands with soap and running water?	a. thoroughness b. physical removal	a. authority b. subjectivity
3. Which of the following is most effective in preventing droplet transmission of disease?	a. containment b. contamination c. distance	a. contamination b. distance
4. Is antibiotic resistance an example of evolution?	a. personification b. natural selection c. heritability d. unsure	a. natural selection b. anthropocentrism c. personification d. mutation e. heritability f. over time g. body is resistant
5. How do mutations which can lead to antibiotic resistance happen in bacteria?	a. foundational learning	a. personification
6. When should a patient be prescribed antibiotics?	a. viral versus bacterial b. prevent resistance	a. prevent resistance b. viral versus bacterial
7. When should a patient stop taking antibiotics that are prescribed to them?	a. prevent resistance b. prevent infection	a. prevent infection b. prevent resistance c. authority
8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?	a. it depends b. patient care c. speed	a. prevent resistance b. speed
9. Which of the following can contribute to a rise in antibiotic resistance?	a. food chain b. anthropocentrism c. exposure	a. exposure
10. Should a patient take the same antibiotic more than once?	a. prevent resistance b. body is resistant c. use correctly	a. worked the first time b. prevent resistance c. unsure
11. Which of these is the only effective treatment for bacterial infection?	a. it depends	a. present versus future b. unsure

Question 1. When should one remove gloves in a clinical setting?

In the control semester (Fall 2020), the recorded codes before and after the lab activity were **contamination** (22 responses), **precaution against disease** (12 responses), **cleanliness** (two responses), **anthropocentrism** (one response), and **personal experience** (one response). The anthropocentric response focusses on the benefit of gloves for the wearer. Many responses overlapped in codes, especially in post-lab responses, as students related preventing contamination to taking precautions against disease:

> "Gloves should be removed when there is even the slightest chance of cross contamination that can cause other diseases." (Victoria, post-lab questionnaire)

One student focused on her own **personal experience** in both her pre- and post-lab rationales, despite changing her answer to the multiple-choice item from an incorrect to a correct response:

> "I personally work as a phlebotomists *[sic]* at [location] & I personally only change gloves when I am going to work with another/different patient" (Bedelia, pre-lab response)

While this student's experience as a healthcare worker in a clinical setting should have exposed her to stricter training about aseptic technique, it is clear that her experience was not as easily generalizable to other clinical practice as she first thought, as in her post-lab response, she changes the tense of "I personally only **change** gloves" in her pre-lab response to "I personally only **changed** my gloves" in her post-lab response (emphasis mine).

In the experimental semester (Spring 2021), codes recorded before and after the lab activity were **contamination** (19 responses), **precaution against disease** (12 responses), **cleanliness** (four responses), and **anthropocentrism** (one response).

As in the control group, the anthropocentric response focused on the gloves as a tool to prevent the wearer from disease:

> “Gloves are meant to **protect both the patient and the doctor** from potentially pathogenic microbes. Therefore gloves should be utilized when coming in **personal contact with patient**, such as in a clinical setting.” (Selena, pre-lab questionnaire)

There was some overlap of codes in responses, especially between **contamination** and **precaution against disease**. When citing precaution against disease as a reason to wear gloves, some students used more specific language in post-lab responses than pre-lab responses, as in:

> “Germs can be spread very easily and cause **HAIs** [healthcare-associated infections]” (Lisbet, post-lab questionnaire)

As students researched antibiotic resistance to complete their I SEE activity, they may have come across this more specific language and integrated it into their vocabularies.

Question 2. Which of the following is as effective as cleaning one’s hands with soap and running water?

In the control group (Fall 2020), codes found in students’ responses were **thoroughness** (eight responses), **physical removal** (six responses), **authority** (three responses), **ingredients** (three responses), and **precaution against disease** (one response). Many students also expressed preferences in their responses:

> “70% alcohol hand sanitizers are still effective. **But washing hands with soap and water is preferred**.” (Ariana, post-lab questionnaire)

Other students emphasized what **ingredients** were used in a given technique, usually to explain the efficacy of 70% ethanol, as in a hand sanitizer:

> “Using hand sanitizer that has at least 70% alcohol content will kill 90% of microbes present” (Dagoberto, post-lab questionnaire)

Some instead placed more emphasis on the **thoroughness** of the motions used to wash one's hands:

> "I would say that none of these are as effective because when hand washing you can thoroughly make sure you care *[sic]* cleaning your hands properly and not missing an area still contaminated with bacteria." (Dhaani, pre-lab questionnaire)

In the experimental group (Spring 2021), codes were **authority** (five responses), **subjectivity** (five responses), **motion** (four responses), and **precaution against disease** (one response). Rationales citing authority were often vague, as in:

> "Washing hands with soap and warm water for around a minute **is found to be the most effective** at preventing microbial growth." (Skye, pre-lab questionnaire)

Subjectivity in responses included students' personal opinions or observations, as in:

> "I guess the 70% alcohol content would be effective, but using it often **would result in damage to the skin if frequently used without moisturizing**. But the best Beth of us *[sic]* washing one's hands with soap and water." (Tess, post-lab questionnaire)

These opinions generally included a caveat to their answer choice of *D. None of the above are as effective as cleaning one's hands with soap and running water*, so that they could express which option they believed was second best after washing with soap and running water.

Students who mentioned **motion** in their rationales often seemed to think that what made washing one's hands with soap and water most effective was the physical rubbing together of one's hands:

> "The 70% alcohol will kill most microbes but **the mechanical motion** and emulsion of soap and water will do a better job." (Theodora, pre-lab questionnaire)

The response citing **precaution against disease** seemed to focus on the number of microbes eliminated by each hand hygiene technique:

> "Because hand washing is able to **eliminate the most germs**, the others will still more than likely leave a good amount of germs on your hands." (Shanice, pre-lab questionnaire)

Question 3. Which of the following is most effective in preventing droplet transmission of disease?

In the control group (Fall 2020), codes found in student responses before and after the lab activity were **containment** (11 responses), **contamination** (seven responses), **distance** (five responses), **completeness** (four responses), **COVID** (four responses), **velocity** (one response), **authority** (one response), and **probability** (one response). **Containment** referred to a method's ability to capture respiratory droplets or pathogens. **Completeness** referred to a method's coverage—for example:

> "The mask covering your nose and mouth is the most effective because **the face shield doesn't seal**, if you cough in your hand now anything you touch, you are spreading your germs and the air droplet might travel further than 3 feet." (Erica, post-lab questionnaire)

The student whose rationale included **probability** was careful to emphasize that no method would provide complete protection from droplet transmission:

> "If there is social distancing, there is a less chance *[sic]* that droplets will reach a person. Masks are effective but not as effective as making sure there is distance between people and possible chance of droplets to reach someone." (Victoria, pre-lab questionnaire)

In the experimental group (Spring 2021), codes found in student rationales were **contamination** (19 pre-lab responses; 14 post-lab), **distance** (eight responses), **protect** (three responses), **COVID** (one response), and **opinion** (one response).

Contamination was often brought up as a reason *not* to use a certain method:

> "…Coughing into your elbow doesn't directly get rid of droplets since some will still get in the air, and it also contaminates the clothing which could in turn spread it." (Sínead, post-lab questionnaire)

Students brought up **distance** to explain that at least six feet were required between individuals, or that encountering the barrier of a mask would decrease the distance travelled by droplets or viral particles.

> "…maintaining 3 feet of distance is not far enough, it must be 6 feet." (Stephanie, post-lab questionnaire)
>
> "The mask will reduce droplets to a few centimeters." (Theodora, post-lab questionnaire)

Their experiences with **COVID-19** and the ways in which the pandemic affected their lab experience also informed their responses to this question:

> "it is most effect *[sic]* because it is in the lab guidlines *[sic]*." (Audriana, post-lab questionnaire)

Students also presented **opinions** about what measures to take that were not options in the multiple-choice item:

> "…Preferably I would do both and wear a disposable mask with a reusable mask over it for extra protection or even doing all of the above." (Ava, post-lab questionnaire)

Question 4. Is antibiotic resistance an example of evolution?

In the control group (Fall 2020), codes found in student rationales were **personification** (12 responses), **natural selection** (seven responses), **heritability** (five responses), **unsure** (five responses), **anthropocentrism** (four responses), **over time** (three responses), **change** (three responses), and **other foundational learning** (one pre-lab response). **Personification** was applied whenever students ascribed characteristics like desires, feelings, goals, or perceptions to bacteria or other microbes that were not appropriate:

> "**They learned that antibiotics can kill their cells and have evolved in order to stay alive** and cause damage." (Dhaani, pre-lab questionnaire)

Anthropocentrism centered the actions of humans as causative of the evolutionary process:

> "**Overuse and misuse** of antibiotics have led to microbes mutating and becoming increasingly resistant towards antibiotics" (Dagoberto, post-lab questionnaire)

Over time defined evolution as a gradual process that must occur over an extended period of time:

> "I believe so because some bacteria weren't always resistance *[sic]* and only became resistant **after some time period**." (Purbita, pre-lab questionnaire)

Change implied evolution requires a constant state of noticeable change:

> "In a way it is, because antibiotic resistance is **always changing and varies from person to person**. It was way different when it first started and how far researchers and doctors have came *[sic]* now. So yes, it is an example of evolution because **it is always changing and never the same**." (Victoria, pre-lab questionnaire)

Other foundational learning was used when a student referenced something they had learned prior to the lab which informed their answer to the question:

> "I am uncertain, but I believe this has something to do with **plasmids** and bacteria. **The genes carried in plasmids provide bacteria with genetic advantages,** such as antibiotic resistance. How it relates to evolution, I'm not entirely sure." (Dorothy, pre-lab questionnaire)

In the experimental group (Spring 2021), codes isolated from student responses were **natural selection** (nine responses pre-lab; six post-lab), **mutation** (eight responses), **body is resistant** (four pre-lab responses; eight post-lab), **heritability** (six responses), **over time** (six responses), and **change** (two responses). The **body is resistant** misconception was even given even in rationales for selecting the correct answer, *A. Yes*:

> "our immune systems **develop resistance with the more antibiotics given** over time" (Sara, post-lab questionnaire)

> "I think it is an example of evolution because as years go on **many people become resistant because of their parents or family**" (Tawny, post-lab questionnaire)

Only one student appeared to reject this misconception after participating in the lab activity, though she retained misconceptions relating to bacterial **personification** (e.g. resistance is a result of bacterial memory):

> "Antibiotic resistance is an example of evolution by natural selection. As humans evolve, **we become more resistant to the antibiotics we are commonly given**, therefore making the bacteria more immune to them." (Artazia, pre-lab questionnaire)

> "Antibiotic resistance is an example of evolution due to the basis of antibiotic resistance of which is *[sic]* the adaptability of the organisms in our body to **recognize previous medicines**." (Artazia, post-lab questionnaire)

As in the control group, many students demonstrated at least basic knowledge of natural selection as a process of evolution. However, only students who used this knowledge in their pre-lab rationales used it in their post-lab rationales.

Students who used the **change** theme in their rationales seemed to have a poor grasp of what exactly constitutes an evolutionary process, and instead see any noticeable change over time as evolution:

> "Well, evolution **in a sense that it has changed and is different than the past versions of the species**. It has gained an advantage that the ones in the past did not have based on their environment and conditions." (Tess, post-lab questionnaire)

Misconceptions related to bacterial **personification**—for example, how they undergo evolution consciously to gain favorable traits—were present in this group's rationales:

> "Antibiotic resistance is evolving **to become stronger**." (Shareen, post-lab questionnaire)

Student responses relating to **anthropocentrism** blamed the actions of humans for the evolutionary processes experienced by microorganisms:

> "Kind of? It is **mainly the result of physicians prescribing too many antibiotics and people taking them wrong**. But the bacteria mutating to survive antibiotics and sharing that with horizontal transfer seems like evolution to me. they *[sic]* are trying to survive." (Suzanne, pre-lab questionnaire)

In Suzanne's case, despite having learned in some detail how genetic information may be disseminated in bacteria ("sharing that with horizontal transfer"), she focuses on the actions of humans and personoifies the bacteria ("they are trying to survive").

Question 5. How do mutations which can lead to antibiotic resistance happen in bacteria?

In the control group (Fall 2020), codes found in student responses were **foundational learning** (six pre-lab responses; four post-lab), **anthropocentrism** (three pre-lab responses; one post-lab), **unsure** (three responses), **personification** (two pre-lab responses; four post-lab), **heritability** (one response), and **authority** (one post-lab response).

Students referring to **foundational learning** described things they had learned previously in lecture or lab (or prior to that, in another course) that helped them to answer this question:

> "I don't really know, but I know that **when we talked about biofilms we never talked about mutations within them** so I think that one is wrong." (Erica, pre-lab questionnaire)

Anthropocentrism centers humans or analogizes unrelated processes in bacteria to those in humans:

> "**Just like how we gain antibodies from being exposed to bacteria, they can build up resistance to antibodies**. Mutations are a random occurrence. Maybe cells are able to communicate about antibodies *[sic]*." (Aoife, pre-lab questionnaire)
>
> "I think that **mutations that lead to antibiotic resistance happen in the presence of an antibiotic** because you would need to be exposed to the antibiotic in order to become resistant to it." (Deborah, pre-lab questionnaire)

Heritability, rather than used to focus on how mutations *arise*, was used to determine how mutations are passed on and *persist* in a bacterial population:

> "The resistant bacteria will reproduce and **pass on the resistant gene to their off-spring** *[sic]*." (Crystal, pre-lab questionnaire)

In the experimental group (Spring 2021), codes found in students' responses to this question were **personification** (six responses pre-lab; seven post-lab), **natural selection** (four responses pre-lab; three post-lab), **communication** (two responses pre-lab; four post-lab), **authority** (two responses), **horizontal gene transfer** (two responses), **anthropocentrism** (two responses pre-lab; one post-lab), **unsure** (two responses pre-lab; one post-lab), **selective pressure** (one response), **body is resistant** (one response), and **immunity** (one response).

Students were again fixated not on how the mutations arose, but how those mutations *persist* in bacteria. Many students talked about the transfer of genes (either through heritability or through horizontal gene transfer) rather than the genes themselves. Those who did address the origin of mutations personified the bacteria undergoing them:

> "the bacteria **mutates to become resistant and unaffected** to *[sic]* the antibiotics" (Sonja, post-lab questionnaire)
>
> "Antibiotic resistant *[sic]* is when the antibiotic fails to treat the bacteria, because the **bacteria rejects the antibiotic** some reasons for this are people not using antibiotics correctly or the person may have resistant *[sic]* that is unseen." (Shanice, post-lab questionnaire)
>
> "When introduced to an antibiotic they **learn to become resistant** to it because they multiply a lot." (Matilda, post-lab questionnaire)

Question 6. When should a patient be prescribed antibiotics?

In the control group (Fall 2020), codes found in students' responses were **viral versus bacterial** (12 responses pre-lab; eight post-lab), **prevent resistance** (seven responses pre-lab, 12 post-lab), **patient care** (three responses pre-lab; five post-lab), **prevent**

infection (three responses), **maybe not sick** (two responses), **better safe than sorry** (one response), **personal experience** (one response pre-lab), and **authority** (one response).

The student whose response fell into the **personal experience** category ascribed her correct answer to her experience with antibiotic prescription:

> "Iv'e *[sic]* never been prescribed antibiotics until I have been diagnosed with an issue." (Aoife, pre-lab questionnaire)

After participating in the lab activity, this student gave a more generalized rationale to her correct answer, this time citing the importance of preventing misuse:

> "Someone should only use antibiotics if diagnosed so they are used only when needed. If not, the bacteria in our body could build resistance to the antibiotic." (Aoife, post-lab questionnaire)

Students' focus on **patient care** mostly emphasized the harm unnecessary prescription could do to a patient and even the patient's microbiome:

> "You shouldn't give medicine to someone who may be expose *[sic]* because without knowing for sure and giving medicine without an infection is pointless and **can do harm**" (Olivia, post-lab questionnaire)
>
> "antibiotics should definitely be used more sparingly as to not contribute to the rise of antibiotic resistance and giving a patient antibiotics unnecessarily can **harm their normal microbiota**" (Amanda, post-lab questionnaire)

Emphasis on **preventing infection** largely centered around stopping the spread of infection from one patient to another:

> "So that the bacteria will **not be able to spread**" (Ariana, pre-lab questionnaire)
>
> "All of the above are appropriate reasons to prescribe antibiotics because the antibiotics can be helpful in **stopping the spread of a bacterial or viral infection** if

there is a potential for the individual to be exposed, and antibiotics are also obviously prescribed when the patient actually has the bacterial or viral infection." (Deborah, pre-lab questionnaire)

Caveats that patients **may not be sick** just because they are exposed, as suggested in answer choices *A.* and *B.*, all accompanied correct answers.

"When they are diagnosed because the infection is known to be present in the body and the antibiotics can be used to treat it. **Just because someone is exposed does not mean they have the infection**." (Dierdre, pre-lab questionnaire)

Expressions that antibiotics are necessary even in exposure (**better safe than sorry**) only occurred with the answer choice *D.*:

"When someone comes in contact with someone who has a virus's *[sic]* or infection, **they have a percentage of getting whatever they came in contact with**. When someone does have a virus or bacteria infection*[sic]*, medicine can cure except covid-19 *[sic]*" (Olivia, pre-lab response)

This student answered correctly after the lab activity, with her focus shifting to **patient care**.

Only one student made a vague reference to **authority**:

"It should only be taken **as advised**" (Purbita, post-lab questionnaire)

In the experimental group (Spring 2021), codes from students; responses were **preventing resistance** (19 responses), **virus versus bacteria** (11 responses), **overprescription** (four responses), **prevent infection** (three responses pre-lab), **speed** (two responses), **patient care** (two responses pre-lab; one post-lab), **body is resistant** (one response pre-lab; two post-lab), **patient compliance** (one response pre-lab), and **it depends** (one post-lab response).

Students' understanding that antibiotics do not work on viruses was often cited in rationales for selecting the correct answer—however, these did not necessarily ensure that these students knew what infections were bacterial and which were not:

> "Antibiotics can not *[sic]* protect a person from a viral infection, so the only other option is when they are diagnosed with a **bacterial infection such as a cold, or cough**." (Teagan, pre-lab questionnaire)

While this student seemed to demonstrate a low understanding of what caused colds and coughs (typically, respiratory viruses) before the lab activity, she selected more accurate examples for her post-lab rationale for the same correct answer:

> "Antibiotics should only be taken to treat certain **bacterial infections like strep throat or a UTI** [urinary tract infection]. Antibiotics do not work for viral infections." (Teagan, post-lab questionnaire)

Overprescription was coded as separate from **preventing resistance** because students did not necessarily connect overprescription or misuse with resistance, but rather with a more vague concept of harm:

> "only when infected is best to **keep the patient from over exposure** to antibiotics" (Sonja, post-lab questionnaire)

Patient compliance, too, was focused more on ensuring efficacy of the prescribed antibiotic rather than the contributions of noncompliance to selective pressure for resistant strains:

> "it is never bad to be prescribed antibiotics, **BUT once prescribed, the dose must be finished** to ensure it works fully." (Stephanie, pre-lab questionnaire)

The code most associated with incorrect responses was **speed**, which placed priority on the speed at which an infection could be addressed using antibiotic treatment. Typically, rationales including **speed** were given with answer choice *D.*:

> "I picked this because it's **important to kill the bacteria fast** so it will do less harm to the host." (Shanice, pre-lab questionnaire)
>
> "antibiotics are very important in protecting the body. any symptoms or sign *[sic]* of a bacterial infection **should be treated immediately** to avoid serious illness to delevop *[sic]*." (Tonantzin, pre-lab questionnaire)

Notably, despite picking an answer choice that includes the use of antibiotics for *viral* infections, each of these students took care to include mention of *bacterial* infections specifically, indicating that they were at least somewhat aware that antibiotics are ineffective against viral infections.

Question 7. When should a patient stop taking antibiotics that are prescribed to them?

In the control semester (Fall 2020), codes from student rationales were **prevent resistance** (nine responses pre-lab; 13 post-lab), **prevent infection** (five responses pre-lab; four post-lab), **authority** (three responses pre-lab; two post-lab), **unsure** (Two responses pre-lab; one post-lab), **personification** (one response), and **personal experience** (one response pre-lab). There was some overlap between **prevent resistance** and **personification**:

> "If patient *[sic]* only takes antibiotics until they feel better – they have not killed off all harmful bacteria from their system. That harmful bacteria **can then familiarize self** *[sic]* with the antibiotic present and **evolve to be able to survive when that antibiotic is present again**" (Bedelia, post-lab response)

Others got closer to describing the selective pressure exerted by partial doses of antibiotics:

"Bacteria develop resistance to antibiotics when the antibiotic is not given the full prescription because they were able to **build a resistance and continue to reproduce.**" (Deirdre, post-lab response)

However, these students still retained the misconception that resistance is "built" or created as a result of the presence of the antibiotic, and not that only resistant bacteria survive and reproduce following exposure to antibiotics.

Use of **authority** in rationales implied that the prescriber should not be questioned:

"The **doctor prescribed that amount of medicine for a reason**, if they wanted you to take less they would give you less. If we don't finish the full prescription we don't fully fight off the virus and create super viruses." (Erica, pre-lab questionnaire)

"**Patients should follow the doctor's orders** on the amount of time that they should take the medication." (Maxine, pre-lab questionnaire)

Rather than connecting antibiotic misuse to resistance or other ill effect, these reasonings were based on the infallibility of prescribers as the driving reason for the correctness of answer choice *A*.

Focus on **preventing infection** largely centered around infections "coming back" after improper antibiotic use:

"If don't *[sic]* take full prescribed medication **the bacteria could still be present and infection can reoccur**" (Alejandra, pre-lab questionnaire)

"if stopped before prescribed, the bacteria **will not all be killed**" (Danica, pre-lab questionnaire)

Personal experience was used in a rationale when a student appeared to not have a good grasp of scientific reasoning behind her answer:

"I was always told to take my prescriptions as directed by my doctor." (Purbita, pre-lab questionnaire)

In the experimental group (Spring 2021), codes used were **preventing infection** (15 responses pre-lab; 12 post-lab), **preventing resistance** (eight responses pre-lab; 10 post-lab), **authority** (eight responses pre-lab; five post-lab), **side effects** (two responses), **misuse** (two responses post-lab), and **personal experience** (one response pre-lab).

As in the previous semester, students citing the **prevention of resistance** in their rationales appeared to make only surface-level connections between antibiotic misuse and resistance:

"To ensure all bacterial cells are dead, and to **avoid the creation of antibiotic resistance** *[sic]* bacteria." (Matilda, pre-lab questionnaire)

"One of the ways to control the use of antibiotics **in order to prevent increased antibiotic resistance** is to avoid abusing medication, i.e., taking too much or too little. It is important to follow prescription *[sic]* for the bacterial infection to be properly treated." (Giulia, post-lab questionnaire)

Preventing infection again focused on preventing infections from re-occurring when bacteria are incompletely treated:

"it's important to get the full dosage of antibiotics **so the bacteria does not come back in any way**" (Sonja, post-lab questionnaire)

Authority was a very common response, which again implied infallibility of prescribers' orders::

"only follow those from a **professional doctor who knows what is better**" (Julianna, post-lab questionnaire)

Students in this group more specifically described antibiotic **misuse**:

> "They should stop when the prescriber tells them to **so they can avoid distributing them wrongly.** It could end up in the sewer which contributes to antibiotic resistance." (Tiffany, post-lab questionnaire)

Uniquely, this group also focused on potential **side effects** experienced while taking antibiotics, mainly as a rationale *not* to rule out answer choice *C. When the patient's symptoms begin to worsen*:

> "The patient should always follow directions from their provider. If they feel better, they can stop taking antibiotics because it is probably working. However, if it gets worse, they should stop **as the antibiotics could be causing a reaction**." (Valeria, pre-lab questionnaire)

Question 8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?

In the control group (Fall 2020), codes from student responses to this question were **it depends** (seven responses pre-lab; nine post-lab), **patient care** (nine pre-lab responses; eight post-lab), **trial and error** (two pre-lab responses), and **personal experience** (one pre-lab response). Students mentioning a concern for patient care fixated mainly on not giving patients medication that they do not need:

> "Not all treatments target certain infections. Best to wait **than to cause more damage**." (Crystal, pre-lab questionnaire)

When stating that **it depends** on other circumstances what an "ideal course of action" should be, students often pointed out that antibiotic drugs should really be prescribed on a case-by-case basis:

> "Either would be effective course of treatment *[sic]*, because if a patient needs medication urgently then a broad-spectrum antibiotic can be used. If the care is not

urgent and can be narrowed down to a specific bacterium then a narrow-spectrum antibiotic can be used." (Caroline, post-lab questionnaire)

Others were more concerned with a patient suffering symptoms of infection for longer than necessary:

> "I think that a prescriber's ideal course of action would be to immediately begin treatment with a broad-spectrum antibiotic **to give the patient some relief**…" (Deborah, pre-lab response)

Students mentioning **trial and error** talked about administering a broad-spectrum antibiotic, then using the patient's response to that antibiotic as part of the diagnostic process in order to find an effective treatment:

> "begin with a broad spectrum antibiotic to **see if it helps and if not then try to find something more specific**" (Purbita, post-lab questionnaire)
>
> "A broad spectrum is useful in unknown cases, **then once diagnosed a narrow antibiotic** *[sic]* **can be added**" (Danica, post-lab questionnaire)

Speed included students' responses placing efficiency of treatment as a priority:

> "In case you want **faster results** then you could take the broad spectrum antibiotic" (Jaelynn, post-lab questionnaire)

Use of this code showed a sharp decrease after participation in the lab activity.

Preventing resistance identified broad-spectrum antibiotic use as contributing to antibiotic resistance:

> "This would be the best course of action because the infection can be treated correctly and also **prevent any mistreatment or resistance that could happen if a broad-spectrum antibiotic is used first.**" (Dagney, pre-lab questionnaire)

The single response including a description of a student's **personal experience** was used to explain the student's selection of answer choice *C.*:

> "…A narrow-spectrum antibiotic treatment should be given only when the infection is known. **At the doctor's I am given two different pills. One is before they actually receive the culture and one is after once** *[sic]* **the culture has been looked at and verified**." (Victoria, pre-lab questionnaire)

After participation in the lab activity, this student selected answer choice *C.* again, but re-framed her rationale in a more hypothetical, rather than first-person, approach.

In the experimental group (Spring 2021), codes from students' responses were **preventing resistance** (nine pre-lab responses; 11 post-lab), **speed** (five pre-lab responses; three post-lab), **play it safe** (two responses), **stop spread** (two pre-lab responses; four post-lab), **trial and error** (one pre-lab response; two post-lab), **unsure** (one pre-lab response), and **personal experience** (one post-lab response).

In this group of students, use of the **it depends** code decreased, and **preventing resistance** increased, often associated with a change from an incorrect pre-lab answer to a correct post-lab answer:

> "While waiting to know exact cause would be helpful **it can be better in some cases** to give immediate treatment as to help with an pain *[sic]* or discomfort that the patient is experiencing." (Eunice, pre-lab questionnaire)
>
> "Waiting to prescribe and antibiotic will help slow the antibiotic resistant bacteria from appearing" (Eunice, post-lab questionnaire)

One student appeared to understand before the lab activity that the immediate use of broad-spectrum antibiotics can contribute to resistance, but answered *B. Immediately begin treatment* *with a broad-spectrum antibiotic* anyway, apparently because she thought that is what the average prescriber would do:

> "I feel they usually just play on the safe side and just guess bacterial infection and start a broad spectrum antibiotic. Glad hey *[sic]* are trying to help people but **they are making antibiotic resistant strains** of bacteria." (Suzanne, pre-lab questionnaire)

In this group, students responding with **patient care** concerns again largely focused on alleviating unpleasant symptoms with more rapid treatment, but one student focused on how immediate broad-spectrum antibiotic treatment might negatively impact a patient's microflora:

> "This is the ideal course of action because narrow-spectrum antibiotics, through their specificity, reduce the changes of selection for resistant bacteria and **harm to one's normal microbiota**." (Giulia, post-lab questionnaire)

Make illness worse and **stop spread** were concerns of students who advised immediate treatment with broad-spectrum antibiotics expressly to stop infections from worsening:

> "I picked this answer because it's important to take control of the bacteria **so it does not grow out of control and cause further damage**." (Shanice, pre-lab questionnaire)

Again, students used **trial and error** to recommend using a broad-spectrum antibiotic as a part of the diagnostic process:

> "A broad-spectrum antibiotic can help with **understanding what type of infection it is**" (Lisbet, post-lab questionnaire)
>
> "They could do both in **order to find out what the exact infection is**." (Tanji, post-lab questionnaire)

Question 9. Which of the following can contribute to a rise in antibiotic resistance?

In the control group (Fall 2020), codes from students' responses were **food chain** (11 pre-lab responses, 10 post-lab), **anthropocentrism** (five responses pre-lab; six post-lab), **exposure** (five responses), **body is resistant** (two responses), **unsure** (two pre-lab responses; one post-lab), **authority** (one pre-lab response; two post-lab), **mutations** (one pre-lab response; two post-lab), and **personification** (one pre-lab response).

Students who talked about the **food chain** described how antibiotic drugs could travel up trophic levels:

> "Antibiotics used in livestock **cause humans to ingest those antibiotics**, leading to a resistance." (Maxine, post-lab questionnaire)
>
> "…**We consume the livestock, which means we are eating what they ate**. Individuals will sometimes flush their medication down the toilet, which allows the antibiotics to dissolve in the water." (Dhaani, post-lab questionnaire)

Anthropocentric responses centered the actions of humans specifically and most often occurred as rationales for selecting answer choice *C. Inappropriate antibiotic prescribing practices*:

> **"inappropriate prescribing antibiotic** *[sic]* can make bacteria in your stomach resistant so if you do get sick and antibiotics is given *[sic]* to you, it may not work" (Beatrix, pre-lab questionnaire)

Responses mentioning **exposure** more accurately defined the mechanism by which bacteria undergo selective pressure for resistance:

> "**Exposing bacteria** to antibiotics without killing them" (Bethann, post-lab questionnaire)
>
> "again, any unnecessary use of antibiotic gives bacteria the **opportunity to be exposed to it and develop resistances** *[sic]* to it" (Amanda, post-lab questionnaire)

The misconception that the **human body is resistant** to antibiotic was reflected in a few responses to this question:

> "These can all cause antibiotic resistance over time, our body's *[sic]* get use to them *[sic]*." (Alisa, pre-lab questionnaire)

Authority included direct reference to the assigned Ventola (2015) article:

> "I read an article for my prelab #5 that [instructor name] assigned and all three causes were listed. One of the main causes was also overuse of antibiotics by patients." (Victoria, pre-lab questionnaire)

References to **mutation** again implied that resistance could not develop independently, and relevant mutations must occur in the presence of antibiotics:

> "All of these can cause to a rise *[sic]* in antibiotic resistance because they all allow the bacteria to **change and mutate and be able to fight** against the antibiotics." (Dagney, post-lab questionnaire)

In the experimental group (Spring 2021), codes from student responses to this question were **exposure** (seven pre-lab responses, six post-lab), **food chain** (four responses), **body is resistant** (four responses), **selective pressure** (two responses), **heritability** (one pre-lab response, two post-lab), **microbial ubiquity** (one pre-lab response), **authority** (one response), **horizontal gene transfer** (one post-lab response), **unsure** (one response), **public mistrust** (one pre-lab response), and **immunity** (one pre-lab response).

Exposure and **selective pressure** were coded separately because students mentioning exposure did not connect it directly to the process of natural selection, but rather associated frequency and/or level of exposure with the probability of bacteria developing resistance:

> "The more a person is **exposed to antibiotics**, the more likely resistant bacteria will be the ones left and multiplying, which in turn contributes to antibiotic resistance." (Tess, pre-lab questionnaire)
>
> "if you are **constantly exposed to the same antibiotics** you raise your chances of developing antibiotic resistance. bacteria are able to recognize and evolve after being attacked by antibiotics, if in constant exposure the can develope *[sic]* full resistance." (Tonantzin, pre-lab questionnaire)

Students mentioning **selective pressure** answered correctly with the same rationales before and after the lab activity, implying that they already had an adequate grasp of the mechanisms through which antibiotic resistance occurs:

> "Antibiotics in wastewater would serve as a site for selecting antibiotic-resistant bacteria. Bacteria would just undergo natural selection until only the resistant bacteria are left. The same situation occurs when antibiotics are used in livestock. Natural selection for antibiotic-resistant bacteria occurs in the livestock and large populations of resistant bacteria would be present in the livestock. Inappropriate prescription of antibiotic *[sic]* equally creates conditions where natural selection for resistant bacteria occur *[sic]*." (Giulia, pre-lab questionnaire)
>
> "Any situation that increases the availability of antibiotics as an environment to select for antibiotic-resistant bacteria contributes to this rise. Antibiotics in wastewater and livestock provide this breeding ground for antibiotic resistant bacteria and serve as reservoirs for infection through these resistant bacterial strains. Inappropriate prescription also contribute *[sic]* to this unnecessary availability." (Giulia, post-lab questionnaire)

When referring to **authority**, students directly referenced the I SEE-style activity:

“During lab, I **researched all of the causes** of the spread of antibiotic resistance and these were some of the main causes.” (Samiya, post-lab questionnaire)

“I learned this **during our I SEE presentations**.” (Valeria, pre-lab questionnaire)

References to the **food chain**, as in the control group, largely assumed that resistance built up through trophic levels to accumulate in humans:

“antibiotics in waste water and live stock *[sic]* can be transferred to humans- which will higheten *[sic]* the resistance and inappropriate use of treatment can result in the same. too much=adverse affects *[sic]*” (Tanis, pre-lab questionnaire)

Question 10. Should a patient take the same antibiotic more than once?

In the control group (Fall 2020), codes were **preventing resistance** (11 pre-lab responses, 10 post-lab), **body is resistant** (six pre-lab responses; four post-lab), **use correctly** (four pre-lab responses; five post-lab), **unsure** (four responses), **not strong enough** (two pre-lab responses; four post-lab), **drug allergy** (two responses), **personal experience** (two pre-lab responses; one post-lab), and **dangerous** (one post-lab response).

Preventing resistance was coded separately from **body is resistant** because **preventing resistance** focused on antibiotic resistance in bacteria, without the misconception that resistance occurs in the human body. Despite this, many students who selected answer choice *C. No, their body may become resistant to the antibiotic on a second exposure* did not appear to register that the answer choice included this misconception, but instead referred broadly to antibiotic resistance in bacteria:

“The doctor can prescribe a different antibiotic that has similar effects to the more you’re exposed to an antibiotic the more resistant **bacteria cells** *[sic]* in your body are going to become” (Dhaani, pre-lab questionnaire)

Whereas responses coded with **body is resistant** made direct reference to the human body developing resistance to antibiotics:

> "Never take same antibiotics *[sic]* the body grows a resistance towards the antibiotic over a period of time, so if taken again it will not be effective…" (Dax, pre-lab questionnaire)

A few students asserted that the same antibiotic could be taken more than once as long as the patient **took it correctly**:

> "If the patient didn't finish taking the planned course of treatment prescribed than *[sic]* they shouldn't be given the same antibiotic, however, if it is another occurrence then the same antibiotic can be prescribed." (Caroline, pre-lab questionnaire)

Despite the question not specifying the length of time between a first prescription of an antibiotic and a second, students tended to assume that the prescriptions were being given back to back, hence codes **not strong enough** and **dangerous**:

> "If the antibiotic did not work the first time then ints *[sic]* more likely that the bacteria isn't very susceptible to the prescribed antibiotic and therefore a more effective antibiotic is needed" (Dagoberto, pre-lab questionnaire)
>
> "Patients should only take the dose that they are prescribed, overdosing **can cause more damage**." (Victoria, post-lab questionnaire)

Two students referenced their **personal experience** with being prescribed antibiotics in their rationales:

> "The amount of time*[sic]* I have gotten flu or strep, I still take the same antibiotic to make me feel better. So it's okay to take the same antibiotic but only if your body needs it" (Olivia, pre-lab questionnaire)

These students answered correctly, informed by their experience.

In the experimental group (Spring 2021), codes in student responses were **worked the first time** (11 pre-lab responses; 10 post-lab), **preventing resistance** (seven responses), **unsure** (seven pre-lab responses; six post-lab), **time delay** (three pre-lab responses; four post-lab), **authority** (two responses), **personal experience** (two responses), **body is resistant** (two post-lab responses), **side effects** (one response), and **it depends** (one post-lab response).

Affirmative responses (either choice *A.* or *B.*) were often accompanied with explanations that if the antibiotic **worked the first time**, it would work again:

> "antibiotics can help **the same way as the first** as long as the antibiotic doesnt *[sic]* give the person any problems" (Sonja, pre-lab questionnaire)

As seen in the control group, students in the experimental group appeared to misunderstand answer choice *B.* as referring to antibiotic resistance in bacteria rather than in the human body, and overlooked the misconception:

> "Im *[sic]* not completely sure but if the antibiotic worked once it could work again. Although there is a chance that the **bacteria have developed resistance** to that antibiotic." (Selena, post-lab questionnaire)

Likewise, students misunderstood what "sensitivity" meant in answer choice *A.*, instead selecting other responses and giving the rationale described in *A.*:

> "Taking the same antibiotic should be safe as long as there are no changes to **how the body reacts** each time it is used" (Tawny, post-lab questionnaire)

Responses highlighting **preventing resistance** remained steady before and after the lab activity:

> "you can get the same infections multiple times, that does not mean that the antibiotic doesn't work. Avoid taking the same antibiotics back and forth, **this will help prevent resistance**." (Tonantzin, pre-lab response)

Time delay refers to the students' perception that more time between doses of the same antibiotic is preferable:

> "i think *[sic]* it is okay as long as it isn't right after the first use" (Audriana, pre-lab questionnaire)
>
> "as long as the antibiotic is not causing sensitivity **or the patient didn't get the bacteria right after the first dose** the prescription should be okay to take again if necessary" (Sonja, post-lab questionnaire)

Students mentioning **authority** referred to doctors knowing best about what to do in this scenario:

> "Your doctor will give you the best advice on how to treat the infection." (Turner, pre-lab questionnaire)

Students also described **personal experience** with antibiotic prescriptions, only to back up their selection of the correct answer choice:

> "I put yes only **because I've been prescribed the same antibiotic twice**, although I'm not 100% certain on my answer. I feel that being prescribed the same antibiotic twice could lead to resistance, but there's a chance that it would not. I feel that it would depend on the proximity in which you've been prescribed both medications." (Beulah, post-lab questionnaire)

One student alleged that taking courses of the same antibiotic too close together would lead to negative **side effects**:

"There's an increased risk of side effects if you take 2 doses closer together than recommended. Accidentally taking 1 extra dose of your antibiotic is unlikely to cause you any serious harm. **But it will increase your chances of getting side effects, such as pain in your stomach, diarrhoea** *[sic]***, and feeling or being sick**." (Laurence, post-lab questionnaire)

Question 11. Which of these is the only effective treatment for bacterial infection?

In the control group (Fall 2020), codes found in student responses were **it depends** (six pre-lab responses; seven post-lab), **reduce use of antibiotics** (four responses), **authority** (four pre-lab responses; three post-lab), **present versus future** (four pre-lab responses; three post-lab), **preventing resistance** (three responses), **viruses** (three pre-lab responses; two post-lab), and **unsure** (two responses).

Students often used **it depends** to place a caveat on their selection of answer choice *D.*:

"All of these are possible treatments because difference *[sic]* bacteria have different response *[sic]* to different antibiotics and some maybe stronger *[sic]* or weaker than the other and require a stronger treatment than another." (Dagney, psot-lab questionnaire)

Reducing the use of antibiotics was found in students' reasoning for *not* selecting answer choice *A.*:

"These are all options as we **try to reduce the use of antibiotics**." (Daliza, pre-lab questionnaire)

Students referencing **authority** either talked about learning relevant information in class or talked about the reliability of doctors' decisions:

> "They give us antibiotics when we are sick which makes us feel better. Therefore when experiencing symptoms , *[sic]* go to the doctor to get medicine to make you feel better." (Olivia, pre-lab questionnaire)
>
> "All examples were discussed in both [course number] lecture and lab" (Bedelia, post-lab questionnaire)

Often, students who selected answer choices *C.* or *D.* rationalized it using a **present versus future** approach to indicate their confidence in scientific research:

> "I'm sure there is not only way *[sic]* to effectively treat bacterial infections. Some mild cases run their course and be left *[sic]* to the immune system to clear the infection out. A prescribed course of antibiotics is traditionally correct, but **with the introduction of modern technology,** a multitude of possibilities for treatment have arisen." (Chiquita, pre-lab questionnaire)

Preventing resistance was a commonly recurring code, in which students explained that newer treatments should be used in order to decrease exposure of bacteria to antibiotics:

> "…Phage therapy and quorum sensing inhibitors will make it least likely *[sic]* for plaque formation and communication between cells to occur reducing mutations and antibiotic resistance. Using medication until treatment finishes or until the infection resolves is the only way to reduce misuse of antibiotics and treat bacterial infections." (Caroline, post-lab questionnaire)

In the experimental group (Spring 2021), codes were **present versus future** (six responses), **unsure** (five responses), **it depends** (three responses), **more trusted** (three responses), **authority** (three pre-lab responses, two post-lab), and **lazy doctors** (one post-lab response).

In contrast to students in the control group, most students in the experimental group used a **present versus future** argument to indicate confidence in currently-used treatments over newer ones:

> "…Finding other methods to treat bacterial infections **will be very important for the future, but for now,** antibiotics are still effective methods to use." (Tess, pre-lab questionnaire)

It depends involved further information not given in the question:

> "Sometimes antibiotics are the best course of action for bacterial infections running rampant throughout the entire body. Other times, antibiotics aren't needed if the infection is localized and can easily be contained. Treatments not involving antibiotics should be utilized when appropriate." (Sínead, post-lab questionnaire)

Much like **present versus future**, students mentioned how **trusted** antibiotics are as treatment for infection over newer methods:

> "antibiotics have had better testing and research to find the best possible way of getting rid of bacterial infections" (Sonja, post-lab questionnaire)

Authority referred both to the opinions of doctors as prescribers and to the assigned lab material:

> "never use antibiotics unless a medical professional sees the need for it" (Julianna, pre-lab questionnaire)
>
> "I know for sure that antibiotics help fight off these types of infections if the bacterium your *[sic]* working with is not already resistant and I **have read in the chapters** that using viruses that infect bacteria is also a good way to kill it off." (Ava, pre-lab questionnaire)

Uniquely, one student referred to **lazy doctors** as a reason to use antibiotic drugs:

"There are many other ways to treat a bacterial infection, it is just easier for doctors to prescribe antibiotics because they do not want to do more work than they already have to." (Beulah, post-lab questionnaire)

Lab Activity Evaluation Free Response Section

Student answers to the free-response questions included in the post-lab evaluation of the lab activity were first descriptively coded, then pattern coded.

Table 14. Most frequent codes (>5) in free-response answers to each evaluation question.

Evaluation question	Most frequent codes in Fall 2020 (control semester)	Most frequent codes in Spring 2021 (experimental semester)
E1. For the topic(s) above which you rated with "I can explain this well" or "I feel I know a great deal about this and can explain it well", explain how the lab activities helped you to understand these topics better.	a. hands-on/visual b. assigned readings	a. assigned readings b. independent research
E2. For the topic(s) above which you rated with "I still don't understand this" or "I feel I understand this adequately", explain how the lab activity could be improved to enhance your knowledge on the subject(s).	a. greater detail b. hands-on/visual	None greater than 5
E3. Do you feel this lab activity helped you to better articulate and present a strategy to solve a problem?	None greater than 5	a. independent research
E4. How would you rate your overall experience of this activity?	a. building on foundation	a. active learning b. bad group experience
E5. To what extent do you think your experience with this lab activity will help you in your future career?	a. stewardship	a. stewardship

Evaluation Question 1. For the topic(s) above which you rated with "I can explain this well" or "I feel I know a great deal about this and can explain it well", explain how the lab activities helped you to understand these topics better.

In the control semester, codes from student responses to this question were **hands-on/visual** (10 responses), **assigned readings** (seven responses), **IA help** (three responses), **independent research** (three responses), **building on foundation** (two responses), **repetition** (two responses), and **more detail needed** (one response).

Students who appreciated **hands-on/visual** components of the exercise were specifically talking about seeing the results of their Kirby-Bauer assays:

> "…The lab experiments **that showed the results of what bacteria were resistant to antibiotics and chemical germicides helped me visualize** this resistance." (Deirdre)

Students who appreciated the **assigned readings** often mentioned how these readings contextualized the information they were learning:

> "…The pre-lab readings for lab 4 and 5 *[sic]* allowed me to understand how it can occur within our environment and transfer of food supply and on a clinical setting. Even lab 1 started the basis of the foundation of knowledge because it helped us understand the importance of aseptic techniques and how to be utilized *[sic]* in lab to prevent cross contamination between a clinical or work environment and even between patient care." (Caroline)

Some students appreciated special **guidance from their IAs**:

> "We have preformed *[sic]* many lab procedures that deal with antibiotics and having that hands on experience really helped me understand. **As well as during the procedures, my lab instructor explains everything very well**." (Victoria)

Students who undertook **independent research** did so of their own volition, rather than as part of an assigned task, in the control semester:

"The lab activities helped me understand these topics better because I was able to see real life application of the topics **as well as it caused me to look into these topics more after the lab**." (Dagney)

Building upon foundational knowledge was used to describe students' experience with having already learned similar or the same concepts, but using new information presented in the lab activity to better understand these concepts:

"ive *[sic]* taken a lot of classes that talk about this since highschool *[sic]* and im *[sic]* certainly no expert but i *[sic]* feel I can explain the basic concepts pretty well. idk [I don't know] if I really got much new information from lab about this; however, **I do think that lab reinforced what I was already taught and rounded out my knowledge of it**." (Maxine)

Similarly, students benefitted from **repetition** of information about key concepts:

"The lab activities helped my understanding **by repeating the same information again**." (Ebony)

In the experimental group (Spring 2021), codes from student responses were **assigned readings** (six responses), **independent research** (five responses), **active learning** (four responses), **raising awareness** (three responses), **hands-on/visuals** (three responses), **building on foundation** (three responses), **teaching to learn** (three responses), **not fun or engaging** (one response), **disconnected** (one response), and **more detail** (one response).

Students related much of their knowledge about key concepts back to reading the **assigned readings**:

"The pre-lab **readings with information about antibiotic resistance** really helped me understand the concept better. it *[sic]* was especially helpful that we had to answer questions about the readings which actually made me critically think about the concept." (Selena)

Others emphasized that the majority of their knowledge came from the **independent research** they did as part of the I SEE-style activity:

"Our lab activities like the presentation **made me do more research into antibiotic resistance** and therefore helped me have a deeper understanding in antibiotic resistance and healthcare." (Tamzin)

Students appreciated the **active learning** format of the activity, which fostered discussion and alternate perspectives:

"The lab helped **because we worked in a group, in which helped us brainstorm** *[sic]* and understand the content much better." (Tanji)

Participating in presentations to the rest of the class helped students **teach to learn**:

"The lab activities **helped me to understand these topics better because of the presentation we had to give**. This made us do more research to be able to explain it ourselves." (Giulia)

Appreciation of **hands-on/visuals** appeared, as in the control semester, to refer solely to the Kirby-Bauer assays:

"Lab activities help give you a better understanding **by dealing with different types of bacteria**." (Turner)

Raising awareness that the concepts existed in the first place had some importance:

"The lab **not only made me aware of what antibiotic resistance was**, but it allowed me to understand the causes and reasoning behind it as well as how to prevent antibiotic resistance." (Teagan)

One student experienced a **disconnect** between lab and lecture material about these concepts, and felt the lab activity was not **engaging enough**:

> "I feel the lab **really was just another power point** *[sic]* lecture so I didn't really lern *[sic]* much about it from that. I learned most from the lecture." (Suzanne)

Evaluation Question 2. For the topic(s) above which you rated with "I still don't understand this" or "I feel I understand this adequately", explain how the lab activity could be improved to enhance your knowledge on the subject(s).

In the control group (Fall 2020), codes from students' responses were **greater detail** (six responses) **hands-on/visual** (five responses), **students' responsibility** (four responses), **lacking confidence** (one response), **assigned readings** (one response), and **COVID-19** (one response).

The most frequent code in these responses were requests for **more detail**:

> "By the IA making it relevant to the lab experiment or **going more into detail in the PowerPoint**" (Ciara)

Students who mentioned **hands-on/visual** tools either requested informational videos (which were provided to this group of students) or a demonstration Kirby-Bauer assay made by an instructor that they could compare their own plates to:

> "We tested the inhibition of bacteria by antibiotics **but were not shown an example** of what resistance would look like." (Daliza)
>
> "Provide **powerpoints** *[sic]* **or videos** to help visual learners." (Edwina)

Four students took **responsibility** for learning more information outside of class:

> "The lab activity is fine. **I need to put in the work to study this material better.** This lab activity should supplement my knowledge. I still need to gain a greater understanding of my own—that is not a shortcoming of the lab activity." (Dorothy)

One student mentioned changes made to the course format to accommodate university-wide **COVID-19** restrictions as a hindrance to her learning:

> "It's hard to understand completely when **the lab time is cut in half**. Most experiments weren't able to perform ourselves *[sic]* for the same of time so it causes us to not understand the concepts as well. I mainly get my information from the readings and the pre labs." (Ariana)

In the experimental group (Spring 2021), there were fewer student responses to this question, yielding fewer codes. Those found were **more detail** (two responses), **hands-on/visuals** (one response), **not engaging** (one response), **disconnection** (one response), and **student responsibility** (one response).

Again, a student took **responsibility** for her own lack of knowledge:

> "Th *[sic]* activity is good over all **I just need to apply myself more** on learning the material" (Tawny)

One student provided a vague recommendation to make the activity **more engaging**:

> "I don't know but **somehow make it fun instead of jsut** *[sic]* **spouting more random words at us**." (Suzanne)

Another student requested an informational video, apparently not realizing that one was provided:

> "I don't have any that I said this, but maybe ways to improve **would be to provide videos that provide simplified explanations** for those who did not get it might be something to include. I find that watching videos helps me to understand the concepts better as it's visual and said in a different way usually." (Tess)

A student struggled with a **disconnect** between the assigned readings and the lab activity:

"I feel like if I was **able to link the pre lab information with the experiments more I could understand better**" (Shanice)

Evaluation Question 3. Do you feel this lab activity helped you to better articulate and present a strategy to solve a problem?

In the control group (Fall 2020), codes were **lacking confidence** (three responses), **lacking problem solving skills** (two responses), **building on foundation** (two responses), **active learning** (two responses), and **hands-on/visual** (one response).

Many students only expressed being "a little more comfortable" with presenting a problem-solving strategy:

"I feel comfortable explaining the topic, **but I can not propse** *[sic]* **possible solutions** to the problem." (Maxine)

"Although it did help me understand the concepts better **I still think that a little more practice and I'd be more comfortable**" (Dagoberto)

Those who felt "significantly more comfortable presenting solutions" almost all cited an **active learning environment** in the lab as their rationale:

"I feel like the. lab activity *[sic]* helped me become more comfortable **because of the fluidity of the lab and the openness for conversations about antibiotics**." (Duffy)

In the experimental group (Spring 2021), codes were **independent research** (six responses), **lacking confidence** (four responses), **active learning** (four responses), **teaching to learn** (three responses), **more detail** (two responses), **assigned readings** (two responses), **creativity** (two responses), **student responsibility** (one response), **lacking problem solving skills** (one response), **IA guidance** (one response), and **COVID-19** (one response).

Most mentions of **independent research** talked about students using research to better understand concepts, rather than problem solving:

> "**I was able to conduct my own research** and better understand the idea of bacteria *[sic]* resistance" (Tanis)

Students who **lacked confidence** mainly felt unqualified to be the person doing the problem solving:

> "I feel more comfortable understanding antibiotic resistance, **but I would be scared to still say something that was not accurate**." (Teagan)

Students appreciated an **active learning** format:

> "The project about how to solve or minimize antibiotic resistance in future years defiantly *[sic]* help me *[sic]* articulate and critically think of a plan of action. **In many classes students are not encouraged to think critically** and be creative but this lab defiantly *[sic]* helped with that." (Selena)

Others cited **teaching to learn** as a method to become more familiar with material:

> "I do, I felt our team researched a cause and required us *[sic]* to really think. Then, we had to study it and **present it which made me comfortable because I knew what I was talking about**." (Tiffany)

A student cited difficulties with **COVID-19** precautions affecting her lab experience:

> "I do **online lab** for family reasons so I'm a little more limited" (Julianna)

Evaluation Question 4. How would you rate your overall experience of this activity?

In the control group (Fall 2020), codes were **building on foundation** (six responses), **hands-on/visual** (three responses), **active learning** (two responses), **more detail** (one response), and **creativity** (one response).

Many students appreciated their lab activity **building** on knowledge they had before:

"This activity allowed me to **review past material and apply the knowledge retained from the lab activities**. It made me realize I am much more familiar with antibiotic resistance than I originally thought and I can educate others not exposed to this material how to reduce resistance. (Caroline)

Others expressed appreciation for **hands-on/visual** aspects of the activity:

"After the powerpoint *[sic]* I was **excited to see what the results would be from lab**; it also made it more (interesting *[sic]* because there were options that we could choose like tee tree *[sic]* oil, or listerine *[sic]*" (Dawn)

For two other students, the **active** nature of the lab made the biggest impression:

"the activity **allowed you to work w** *[sic]* **others and hear their opinions on the material learned as well as voice your own**." (Chiquita)

In the experimental group (Spring 2021), codes in student responses were **active learning** (11 responses), **bad group experience** (six responses), **building on foundation** (four responses), **independent research** (three responses), **creativity** (two responses), **COVID-19** (two responses), **raising awareness** (one response), **teaching to learn** (one response), and **lacking confidence** (one response).

Having to rely on a group in order to complete the I SEE-style activity was not ideal for everyone, especially with COVID-19 precautions in place:

"**I hate group presentations**. I always end up doing all of the work and we learned nothing. it was truly TRULY *[sic]* a waste of everyone's time. we simply made up a random plan and then read of the slides… ? *[sic]*" (Suzanne)

"Group projects over zoom *[sic]* are **not the best**" (Alexis)

Students who found the activity interesting cited it helping to **build on foundational learning** about antibiotics and resistance:

"I chose this, because I did find it very interesting **and it also allowed me to connect what we were doing in lab with the course material.**" (Teagan)

The majority of students who found the activity interesting expressly referenced the **active learning** nature of the activity:

"I enjoyed **hearing different perspectives and being able to put all our minds together**. We all came up with different ideas so it was good." (Tiffany)

Students cited **COVID-19** as both hindering their experience with the activity and as a reason to enjoy the activity:

"It was really hard to complete **within an online setting**" (Skye)

"It was interesting because we got to take a dive into the future and it felt nice to work with people **even during a pandemic**." (Laurence)

Evaluation Question 5. To what extent do you think your experience with this lab activity will help you in your future career?

In the control group (Fall 2020), codes were **stewardship** (12 responses), **hands-on/visual** (two responses), and **creativity** (one response).

The most frequent code was **stewardship**, in which students described how their experience with the lab activity might help them to responsibly use antibiotics in their future workplaces:

"As i *[sic]* plan to work in a hospital in my future all the information from these activities are really helpful in learning what do *[sic]* when i *[sic]* get there **to help prevent the spread and creation of antibiotic resistant bacteria**." (Dagney)

"When I become a nurse I want to be **fully aware of the consequences that antibiotics have**" (Dawn)

In the experimental group (Spring 2021), codes were **stewardship** (eight responses), **patient education** (three responses), **active learning** (three responses), **lacking confidence** (three responses), **raising awareness** (two responses), **repetition** (one response), and **creativity** (one response).

Again, students expressed an appreciation in the activity for instilling knowledge of antibiotic stewardship:

> "Now that I know the extent and the dangers of antibiotic resistance, **it'll always be in the back of my mind when working in hospital settings and dealing with infections, viruses, and antibiotics**." (Beulah)
>
> "As a nurse, I will have patients who have antibiotic-resistance *[sic]* and would need to prescribe another antibiotic. **I would need to think carefully to make sure I am not contributing to the antibiotic-resistance** *[sic]* **crisis**." (Theodora)

In this group, however, students also expressed that the activity made them better equipped for **patient education** in the future:

> "I am going for nursing, therefore, I will not be the one prescribing medication. However, **now that I have an understanding I know to ask patients if they took their previously prescribed medication correctly**." (Annunziata)
>
> "its *[sic]* going to **help me understand the best medical advice and help to patients know the importance of finishing prescriptions**" (Sonja)

Students also recognized how an **active learning** environment might reflect their future workplace environment:

> "As someone pursuing nursing, **knowing how to articulate a plan to problem solve will help me greatly in the field, as well as working with other individuals**." (Artazia)

Themes From Qualitative Research

Themes isolated from students' responses to the RAUEQ were **authority**, **COVID-19**, **unsure**, **foundational learning**, **prevention of disease**, **patient care**, **prevention of resistance**, **opinion**, **anthropocentrism**, **prevention of resistance**, **cleanliness**, **present versus future**, and **personification**. Table 15 shows how each descriptive code fit within each pattern code, and how each pattern code fit into the themes.

Anthropocentrism refers to language centering the actions of a particular person, or humans in general, or blaming the actions of people for something. Pattern codes within this theme were **anthropocentrism, food chain, protect,** and **body is resistant**. The pattern code **body is resistant** contained both the descriptive codes **immunity** and **body is resistant**. The **food chain** code is anthropocentric because it was used in responses to questions about how antibiotic resistance arising, focusing not on selective pressure of low-grade antibiotic exposure on bacteria, but rather the bioaccumulation of antibiotics in humans as they travelled through trophic levels (e.g. from livestock). **Body is resistant** contains the **immunity** descriptive code because of the reliance of students who used it on analogies to the human body, and the comparison of bacterial physiology to human physiology.

Authority was used when students cited the teaching of a professor, IA, government agency, or an assigned reading as backup for their answers. These included specific mentions of the course and its material, the lab activity, the public health messaging of an agency such as the CDC, and more vague references to outside sources, like "it has been proven" or "I have read." Often, **authority** heavily implied that a healthcare professional is infallible, or that their opinions, prescriptions, or other guidance should not be questioned.

Cleanliness included all mentions of **contamination**, as well as descriptive codes that were used in rationales to the Domain One questions regarding infection control—those relating to the cleaning of one's hands (**thoroughness, physical removal, motion**) and qualities of an effective face covering to prevent droplet transmission of disease (**containment, completeness**).

COVID-19 included direct mentions of COVID-19 or SARS-CoV-2, the word "pandemic," and any discussion of changes in lifestyle or course modality in response to the ongoing COVID-19 pandemic.

Foundational learning included codes that related to concepts students had learned prior to the lab activity concerning antibiotics and antibiotic resistance. This includes concepts previously covered in their introductory microbiology lab (**communication, microbial ubiquity**), the lecture course associated with this lab (**mutation, horizontal gene transfer, viral versus bacterial**), or any other high school- or university-level biology curriculum students had previously taken (**heritability, natural selection, selective pressure, other foundational learning**).

Opinion included all statements which had more to do with students' personal experiences or interpretations of concepts than factual discussion of these topics. This included the **it depends** pattern code, in which students used conditions not presented in the original question or answer choices in their rationales, as well as the **personal experience** pattern code, in which students related the question or concept back to their own life experience(s). This also included other, subjective observations (**subjectivity, probability, lazy doctors, more trusted, not strong enough, public mistrust, trial and error**) in which reference to the students' opinions or interpretations outweighed references to fact.

Patient care focused on providing optimal care to a patient, disregarding other factors and prioritizing patient safety, comfort, and quality of life. It also included mentions of educating a patient about responsible antibiotic use.

Personification included any indication of sentience in microbes—giving them desires, feelings, or aspirations, for example. Rationales including **personification** would anthropomorphize bacteria, especially when implying they would undergo natural processes like mutation or evolution on purpose.

Present versus future was used to code any rationale that compared currently available treatment methods with treatments in development for future use.

Prevention of disease included a few descriptive codes, all of which focused on either stopping a disease from developing or from worsening in a patient or population.

Unsure included any indications that a student was not confident in their rationale, whether that be a string of question marks, phrases like "I don't know" or "I'm not sure", or using world like "might" or "should."

Some descriptive codes were not used frequently and did not fit into any of the established themes, nor did they seem significant enough to provide their own themes. **Speed** fell into the pattern code **speed**, and referred to students' favoring the speed or efficiency of a treatment over any other factor.

Table 15. Overarching themes found in qualitative analysis of RAUEQ free-response rationale data, with the pattern codes and descriptive codes that fall into each broader theme category.

Theme	Pattern code (second cycle)	Descriptive code (first cycle)
Anthropocentrism	Anthropocentrism	Anthropocentrism
	Food chain	Food chain
	Protect	Protect
	Body is resistant	Immunity
		Body is resistant
Authority	Authority	Authority
Cleanliness	Contamination	Contamination

	Cleanliness	Cleanliness
		Thoroughness
		Physical removal
		Motion
	Other codes	Containment
		Completeness
COVID-19	COVID-19	COVID-19
Foundational learning	Heritable change	Heritability
	Foundational learning	Natural selection
		Other foundational learning
		Mutation
		Communication
		Selective pressure
		Horizontal gene transfer
		Viral versus bacterial
		Microbial ubiquity
Opinion	Personal experience	Personal experience
	Subjectivity	Subjectivity
		Probability
		Lazy doctors
		More trusted
		Not strong enough
		Public mistrust
		Trial and error
	It depends	It depends
Patient care	Patient care	Drug allergy
		Worked the first time
		Dangerous
		Patient care
		Maybe not sick
		Patient compliance
		Side effects
Personification	Personification	Personification
Present versus future	Present versus future	Present versus future
Prevention of disease	Precaution against disease	Prevention of disease
		Prevention of infection
		Better safe than sorry
		Stop spread
		Make illness worse
Prevention of resistance	Prevention of resistance	Reduce use
		Prevention of resistance
		Overprescription
		Misuse
		Exposure
Unsure	Unsure	Unsure
Other codes	Speed	Speed
	Other codes	Distance
		Velocity
		Change
		Over time

Themes from students' evaluations of the lab activities were **active learning, new information, negative experience, independence, COVID-19**, and **clinical practice**. The way descriptive codes fit into pattern codes, and pattern codes fit into these themes, is shown in Table 16.

Active learning includes any discussion of a component of active learning—**hands-on/visual** engagement with content, **repetition** of key concepts, **active learning** and discussion between peers, **teaching to learn**, and **creativity** in the classroom.

Clinical practice includes mentions of any skills that a pre-nursing student might use upon entering the workforce and working in a clinical environment, such as **stewardship** of antibiotics and **patient education** about antibiotic use.

COVID-19 again includes mentions of the ongoing COVID-19 pandemic, the SARS-CoV-2 virus, or changes in lifestyle and/or course modality that occurred in response to this pandemic.

Independence involves students doing work on their own and taking responsibility for that work, such as **independent research** and **students' responsibility**.

Negative experience includes any students' mentions of a negative experience with the lab activity or with their peers. These are **more detail needed**, **not fun or engaging**, **disconnected**, **lacking confidence**, **lacking problem solving skills**, and **bad group experience**.

New information refers to anything that exposed students to new course information, including **assigned reading, IA guidance, building on foundation,** and **raising awareness**.

Table 16. Overarching themes found in qualitative analysis of students' responses to the post-lab evaluation questions. Descriptive codes are sorted into pattern codes, which in turn are sorted into themes.

Theme	Pattern code (second cycle)	Descriptive code (first cycle)
Active learning	Active learning	Active learning
		Teaching to learn
		Creativity
	Repetition	Repetition
	Engagement with content	Hands-on/visual
Clinical practice	Stewardship	Stewardship
	Patient education	Patient education
COVID-19	COVID-19	COVID-19
Independence	Independent research	Independent research
	Students' responsibility	Students' responsibility
Negative experience	Bad group experience	Bad group experience
	Lacking skills	Lacking confidence
		Lacking problem solving skills
	Lacking instruction	Disconnected
		More detail needed
		Non fun/engaging
New information	Learning from lab	Assigned reading
		IA guidance
	New information	Building on foundation
	Starting from scratch	Raising awareness

Theme frequencies

The number of times each theme was found in students' free-response rationales in the RAUEQ and responses to the post-lab activity evaluation was descriptively compared between the control and experimental groups.

RAUEQ Free-Response Rationales

Table 17 shows frequencies of each theme in students' pre- and post-lab RAUEQ free-response rationales, as well as the percent change between pre- and post-lab rationales for each group.

Table 17. Theme frequencies and percent change of theme frequencies in pre- and post-lab RAUEQ free-response rationales in the control and experimental groups.

Theme	Control group (Fall 2020)			Experimental group (Spring 2021)		
	Pre-lab frequency	Post-lab frequency	Percent change	Pre-lab frequency	Post-lab frequency	Percent change
Anthropocentrism	30	22	-26.67%	36	25	-30.56%
Authority	11	14	27.27%	19	14	-26.32%
Cleanliness	28	27	-3.57%	29	27	-6.89%
COVID-19	4	2	-50.00%	3	2	-33.33%
Foundational learning	37	23	-37.84%	38	30	-21.05%
Opinion	28	31	10.71%	20	32	60.00%
Patient care	21	20	-4.76%	14	15	7.14%
Personification	18	18	0.00%	7	7	0.00%
Present versus future	2	4	100.00%	3	5	66.67%
Prevention of disease	26	20	-23.08%	42	31	-26.19%
Prevention of resistance	27	36	33.33%	37	54	45.95%
Unsure	22	7	-68.18%	17	11	-35.29

IV. DISCUSSION

In order to address my research questions by evaluating pre-nursing undergraduates' knowledge of antibiotic resistance and stewardship, ascertaining how this knowledge changes after exposure to relevant course content in a laboratory setting, and understanding how students use a scenario planning activity to expand their knowledge, we asked students several questions about antibiotic resistance and stewardship and infection control. This chapter reviews my findings, compares my findings to previous research on undergraduate and nursing students' understanding of and misconceptions about antibiotic resistance, use, and stewardship, and provides suggestions for further research into using scenario planning and other future learning skills in pre-nursing biological sciences curriculum.

RQ 1: The Status of Antibiotic Resistance and Stewardship Knowledge

Students in the experimental group performed significantly better on their pre-lab RAUEQ than students in the control group (t=-2.696; p=0.004). Reasons for this are unclear. Instruction prior to this lab activity, including readings assigned for the pre-lab homework, were as close to identical as we could reasonably control for (with the exception of pedagogical differences between different groups of lab instructors).

Question 1. When should one remove gloves in a clinical setting?

Students' responses fell in line with findings from Chan et al. (2002), showing similar to lower (in comparison with our participants) compliance and knowledge about appropriate glove use in practicing nurses, as 83% of nurses studied used gloves when appropriate. Pre-nursing students require further instruction in universal precautions before entering further nursing education or a clinical setting.

No misconceptions about when gloves should be used stood out in our participants' responses or in the literature, though it was interesting to note that one student in the control group did answer this question incorrectly as a result of her clinical experience as a phlebotomist in a major area healthcare organization. While the experiences of phlebotomists are not the same as those of nurses, they both work with potentially biohazardous materials, and the fact that this student, who works with blood, only felt the need to change gloves between patients and not upon exposure to fluids is concerning. Pre-health professions undergraduates have, in previous studies, shown similar knowledge gaps in when gloves should be used—Ayub et al. (2013) found that only 85% of these students washed their hands before and after glove use, and 91.2% understood that standard precautions must be used for all patients, not just those with bloodborne infections.

Question 2. Which of the following is as effective as cleaning one's hands with soap and running water?

College students in general are a well-studied population in terms of compliance with hand hygiene recommendations. Despite public health messaging, one of the strongest predictors for hand washing compliance in this group is past behavior—if students are not already washing their hands correctly, or using alternative methods of hand hygiene, they are unlikely to change their habits easily (Zhang et al., 2020). In fact, although the COVID-19 pandemic has led to increased public health messaging about hand washing, positive changes in healthcare personnel's hand hygiene habits have been short-lived (Moore et al., 2021). This supports the importance, especially in pre-nursing students, of continued efforts to encourage hand hygiene throughout the instructional process. The general population in the United States varies in their hand hygiene practices, but in general, anywhere from 60-80% of Americans engage in hand washing, at least following bathroom use—though in a study more focused on college students, only about half of these used soap while washing their hands (Botta et al., 2008). Responses from students in this study may have been slightly skewed by gender, however, as multiple studies show female college students show greater compliance with hand hygiene than male students (Anderson et al., 2008).

Nursing students in particular have shown inflated confidence in the efficacy of alcohol-based hand sanitizers, which was reflected in these participants' responses to this question. The majority of nursing students use hand sanitizers incorrectly, reducing their efficacy (Kelcíkova et al., 2011). Even when students adhere to hand hygiene standards, most cannot explain why these standards are necessary from a microbiological perspective (Cox & Simpson, 2018).

Question 3. Which of the following is most effective in preventing droplet transmission of disease?

While students' knowledge of preventing droplet transmission of disease was high, it was surprising that this number was not, in either group before or after lab instruction, closer to 100%. Because students are taking this course during the COVID-19 pandemic, we expected their personal experience to play a part in their selection of the correct answer. Other studies have shown "hyper-vigilance" about prevention of droplet transmission of disease during the pandemic, especially in nursing students currently in clinical placements (Ulenaers et al., 2021). Participants in this study demonstrated knowledge of control of infection via droplet transmission that fell within measures found in other studies of nursing students during the COVID-19 pandemic and other similar respiratory disease events (Fernandes et al., 2021; Kim & Choi, 2016).

Misconceptions about the distance required between individuals to lower the probability of droplet transmission were detected in only a few students, who believed one meter, not two, was the appropriate distance. In the Fall 2020 semester, in which the control group was surveyed, CDC guidance required two meters of distance in between individuals.

However, more confusing guidance was present in the Spring 2021 semester, in which the experimental group was surveyed, when the CDC and other public health figures began to suggest one meter could be sufficient (Bowden, 2021). Healthcare workers surveyed before the COVID-19 pandemic, however, routinely underestimated the distance required between themselves and patients in order to decrease the probability of infection via droplet transmission (Gralton et al., 2013; Mitchell et al., 2014).

Question 4. Is antibiotic resistance an example of evolution?

It is interesting that students in the control group performed better on this question than students in the experimental group, who, through the I SEE-style activity, dedicated more time to considering antibiotic resistance and how it occurs. While both groups of students read the same papers, the experimental group did not appear to make as solid a connection between the concepts of antibiotic resistance and evolution as did the control group students. The experimental group instead appeared more confused—more students changed their answers from a correct answer to an incorrect answer, and more kept incorrect answers.

Misconceptions of what evolution entails are extremely common and well-studied in undergraduate students. The students in this study who answered "no" on this question either assumed that, were resistance an example of evolution, it would be "more common" in people, or that it would have been occurring for longer. The misconception that antibiotic resistance happened in people, not in bacteria, appeared to contribute to some students' incorrect answers to this question, and is one of the most common misconceptions about antibiotic resistance described in other, similar studies (Carter et al., 2016).

Question 5. How do mutations which can lead to antibiotic resistance happen in bacteria?

Evolution and natural selection are concepts which undergraduates in the United States regardless of major struggle with. Even biology majors, in whom these concepts are rigorously tested, often leave courses with significant misconceptions that resist instructional intervention (Bishop & Anderson, 1990; Kalinowski et al., 2013). Misconceptions that organisms undergo natural selection or even mutation by choice—they "want to" or "are trying to"—are exceptionally common (Bishop & Anderson, 1990). This was reflected in both semesters of this study throughout statements coded with **personification**.

Several studies have shown that undergraduate students, whether they are majoring in biology or have prior instruction in relevant concepts or not, confuse the *origins* of genetic variation with the mechanisms by which this variation *persists* in a population (Bishop & Anderson, 1990; Gregory, 2009). This was reflected in the poor performance of students in this study on Question 5, to which the majority of participants responded with rationales describing selective pressure or exposure to environmental factors as bringing about mutations.

Question 6. When should a patient be prescribed antibiotics?

These students' responses are not altogether unexpected—many prescribers believe that antibiotics can be used preventatively or prescribe antibiotics for viral infections (Arnold & Straus, 2009; Patel et al., 2020; Sagaldo-Peralvo et al., 2021). Pre-health professions students have shown several misconceptions about what constitutes appropriate antibiotic use, including that antibiotics are able to treat symptoms of infectious disease (e.g. inflammation) and that they may be used for viral infections (Akbar et al., 2021).

Question 7. When should a patient stop taking antibiotics that are prescribed to them?

The answer to this question is deeply contested in medical circles. Prescribers and public health experts disagree over how beneficial completing a course of antibiotics as prescribed can truly be in preventing antibiotic resistance—however, this remains the recommendation of organizations such as the CDC and WHO, and most professional medical and scientific associations in the world (Grigoryan et al., 2007; Llewelyn et al., 2017; Lopardo, 2017; van Saene et al., 2008). Prescribers who are older and have been in clinical practice for longer often struggle with giving this advice and, often, whether a prescriber tells a patient to finish their course of antibiotics whether they feel better or not depends on that prescriber's exposure to continuing education (CE) materials on appropriate antibiotic use (Hulscher et al., 2010). As a result, many people, including pre-health professions students, are under the impression that antibiotics may be stopped upon feeling better (Akbar et al., 2021; WHO, 2015).

While pre-nursing students will largely never be prescribing antibiotics to patients (unless they pursue further education to become a nurse practitioner, doctor, or physician's assistant), they must be able to reinforce patient education and monitor prescribers' habits in clinical settings to ensure patient safety and outcomes (Ahouah et al., 2019; Charani et al, 2013; Flynn et al., 2012; Wentzel et al., 2016). Therefore, it is important to these students' future roles as part of an antimicrobial stewardship team.

Question 8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?

Despite these students' lack of experience in healthcare fields and with prescribing, their attitudes on this question largely reflect the attitudes seen in prescribers when asked similar questions. Anxiety about the patient's welfare, the speed at which a patient can be treated, and the prescription process as one of trial and error were seen in qualitative interviews with general practitioners (Rose et al., 2021). Although prescribers are not in general agreement over a generalizable answer to this question, its codification in several national prescribing guidelines makes a prescriber's broad:narrow-spectrum antibiotic prescription ratio a useful indicator of participation in antibiotic stewardship programs (Teixeira Rodrigues et al., 2019). Therefore, future nurses' understanding of the context in which either should be prescribed is critical to their own participation in antibiotic stewardship programs.

Another study of nursing students' knowledge of antibiotic resistance showed roughly analogous proportions of students understanding how using a narrow-spectrum antibiotic can mitigate the appearance of resistance, with 53.1% agreeing (Rábano-Blanco et al., 2019).

Question 9. Which of the following can contribute to a rise in antibiotic resistance?

A larger study of nursing students' knowledge of antibiotic resistance found that 91.3% of students agreed that inappropriate prescribing contributes to resistance (Rábano-Blanco et al., 2019). This proportion, and that found in my study, are similar to the proportion of practicing physicians and medical students who believe this (Abbo et al., 2011; Dyar et al., 2016).

Question 10. Should a patient take the same antibiotic more than once?

The general public's understanding of antibiotic prescribing is low. The students in this study presented a rate of understanding roughly analogous to the global general population's, 43% of whom think it is acceptable to use the same prescribed antibiotic more than once (WHO, 2015). Because of the lack of medical consensus regarding this topic, it is poorly studied amongst healthcare professionals, whether they hold prescribing power or not. As a result, we cannot compare these students' understanding to that of similar populations.

Question 11. Which of these is the only effective treatment for bacterial infection?

Even now, prescribers demonstrate significant knowledge gaps when it comes to appropriate use of non-antibiotic therapies such as phage therapy to treat bacterial infections (Gordillo Altamirano & Barr, 2019; Pires et al., 2020; Smith et al., 2018). Likewise, prescribers often inappropriately prescribe a course of antibiotic drugs for self-limiting infections, rather than recommending the management of symptoms (Levin et al., 2014). As such, it is important that newer entries into the healthcare workforce bring in knowledge of cutting-edge treatments, whether they will have the power to prescribe medications or not. These students' generally high confidence in alternatives to antibiotics are promising as they enter a healthcare workforce that is in the process of moving beyond their use (Gordillo Altamirano & Barr, 2019).

RQs 2 & 3: Changes in Knowledge Following Instruction

No statistically significant differences were found in students' mean scores on the RAUEQ following the I SEE-style activity versus the simple instruction in performing a Kirby-Bauer assay. This did not meet our expectations—namely, that students in the experimental group would show a significant increase in correctness over the control group. However, it is interesting to note that students performed significantly better on their post-lab RAUEQ than their pre-lab in the control group (t=-2.084; p=0.020) and not in the experimental group (t=-0.949; p=0.173). It is not immediately clear why the students in the control group performed better than those in the experimental group. Based on responses to the post-lab evaluation questions, many students seemed confused by the increased coverage of the complexities of antibiotic resistance in the experimental semester. Also, students in the experimental group were performing from a significantly higher baseline (that is, pre-lab correctness on the RAUEQ) than were students in the control group. However, our main focus in addressing these research questions was not necessarily changes in scores on a multiple-choice measure of knowledge—rather, we wanted to know *where* those changes occurred in students' conceptual awareness of antibiotic resistance, use, and stewardship.

The biggest differences in the number of students answering questions correctly were seen on questions 2 (hand washing), 4 (evolution), 5 (origin of genetic variation), 8 (appropriate antibiotic use), 10 (appropriate antibiotic use), and 11 (treatments for bacterial infection). The most interesting of these differences were seen on question 4 (25% more students answering correctly in the control group; same amount answering correctly in experimental group) and question 8 (20% fewer students answering correctly in the control group; 22% more answering correctly in the experimental group). We expected poor performance on questions 5 and 10 based on previous studies into undergraduate students' and the general public's understanding of those concepts. However, considering that evolution was not explicitly mentioned or explained in the control group's lab activity, it was a pleasant surprise to find 100% of students recognizing that the development of antibiotic resistance is an evolutionary process.

In both groups, use of terms falling into the **unsure** theme decreased, indicating that students felt more confident in their understanding of which answers were correct following instruction. Frequency of the **anthropocentrism** and **foundational learning** themes also decreased, which is promising. Fewer students approaching antibiotic resistance from an anthropocentric point of view could indicate that these students cast off certain misconceptions about the role of humans in the development of resistance in bacteria. A decreased reliance on foundational learning, too, indicates that students were likely using the new information they had learned in the lab activities to respond to the RAUEQ. Both groups showed a notable increase in the use of terms falling into the **preventing resistance** theme, which likely means they learned about how responsible antibiotic use can prevent the development and spread of antibiotic resistance.

Participants in studies evaluating activities developed as part of the I SEE Project were evaluated more for their conceptions of complex systems and their development of scientific skills than for their conceptual knowledge about the topic, such as how climate change happens. Qualitative analysis of these students showed improvements in these students' ability to understand complexity and feedback, but did not show that students were able to generalize the scientific skills they developed as part of the I SEE activity to other concepts (Barelli, 2017).

Other active learning interventions in undergraduate biology courses showed improvements in conceptual understanding (Cleveland et al., 2017; Freeman et al., 2014). However, instructors' experience and attitudes may play a greater role in the differences previously seen in student understanding of concepts after active learning instruction. Students cannot be expected to make meaningful gains in conceptual understanding if their instructor lacks the appropriate nuance in their approach to teaching (Andrews et al., 2011). Most instructors, especially those who are teaching about complex and difficult concepts such as natural selection (an apt comparison to antibiotic resistance, as they overlap considerably) fail to take students' pre-existing misconceptions into account (Crowe et al., 2018). As a result, any number of novel interventions may be used in a classroom, but if the instructor does not integrate a constructivist approach, students' gains in understanding will not increase (Andrews et al., 2011; Auerbach et al., 2018; Pollock & Finkelstein, 2008).

RQ 4: How Students Used the I SEE-Style Activity

Satisfaction with the lab activities, as determined by students' responses to post-lab evaluation questions, did not differ significantly between the two groups (t=-0.000;

p=0.499). Similarly, no significant difference could be detected in students' perceptions of how the lab activities would help them in their future nursing careers (*t*=0; p=0.5) or their comfort with presenting solutions to a problem (*t*=0; p=0.5). However, the most useful information came from qualitative analysis of students' post-lab evaluations.

Students' resistance to active learning interventions has been well-documented. Any activity—in our case, interacting with others in an uncontrolled out-of-class setting and giving a presentation to their peers—that increases students' anxiety is poorly received (Hood et al., 2021). Effective teamwork must first be cultivated, especially in younger, Generation Z students who lack interpersonal communication skills (Chicca & Shellenbarger, 2018). While a few students in our experimental group expressed emphatic dislike for group activities in general, saying they ended up doing most or all of the work themselves, we cannot conclude that this was the fault of the other students in their groups, or if these students had not developed effective listening skills. First instructing students in listening to understand, shifting focus from themselves to others, and explaining how each student can support one another could have increased their satisfaction with this group activity (Marasi, 2019).

One of the main things students appreciated about the I SEE-style activity was the opportunity to read content outside of the expected lab curriculum. Several students remarked on the utility and interestingness of the assigned readings (Ventola, 2015 and Sturmberg & Martin, 2009), and others enjoyed being able to conduct their own independent research to find other relevant information to work into their presentation on how to mitigate antibiotic resistance. However, they were most thrown off by the new assignment style—used to being graded based on inclusion or exclusion of content in strictly-guided lab assignments, they reacted negatively to the open-ended nature of the I SEE-style assignment.

They had trouble contextualizing the activity into the course curriculum, complaining that it did not help them on exams or relate to what they were currently learning in the lecture part of the course. For this reason, we believe that this intervention would be best suited to a microbiology lab that builds up active assignments more gradually, and helps to train students in how to work together effectively and make decisions.

Summary

Importance of Active Learning in Pre-nursing Education

As students leave a traditional education setting—wherein they are passive listeners to lectures, take exams where there are clearly delineated right and wrong answers, and rarely relate concepts between disciplines—and enter further nursing education and the workforce, they must undergo a cognitive shift. Currently, students are not handling this shift well, and deal with feelings of insecurity in their knowledge and skills (Smith & Coleman, 2008). While the need for problem-solving skills in healthcare is obvious, students must also develop their problem-*finding* skills, in which they are able to identify an issue and its several components, in order to begin solving problems (Liu et al., 2021). The need, too, for independent inquiry and reflexivity skills, as well as self-regulated learning, has also been identified by numerous nurse educators around the world, but traditional methods of education, especially in the biological sciences, lack the tools necessary to begin exposing students to these methods of thinking (Irvine et al., 2021; Liu et al., 2021).

Required science curriculum in pre-nursing programs can set students up to fail. Students feel intimidated by the depth of scientific information, and often have not yet been exposed to methods of scientific thinking (Chan et al., 2019). Lacking organizational skills, the ability to concentrate, and an understanding of inquiry all hold pre-nursing students back in courses where they tend to feel they are not able to connect larger biological concepts to clinical concepts (Chan et al., 2019; Craft et al., 2017). When students do poorly in these courses, they are more likely to give up on nursing altogether—feeling unprepared for scientific content is a main cause of attrition worldwide (Chan et al., 2019). While students invariably rate lecture-based instruction as their preference, they express feelings of boredom, alienation from the content, and being overwhelmed (Agre & Thomas, 2013; Eberlein et al., 2008).

Active learning has not only been shown repeatedly to enhance students' understanding of course content, it helps students to achieve confidence and decision-making abilities (Agre & Thomas, 2013; Middleton, 2013). However, as also seen in activity evaluations from this study, students who have only experienced traditional learning settings often express distaste for active learning activities and techniques, feeling frustrated with their perceptions that they cannot know whether they are "getting the answer right" as they do not tend to feel a need to pursue scientific knowledge for its own sake (Irvine et al., 2021; Smith & Coleman, 2008). Not only does instructor experience play a significant role in how effective active learning can be (Andrews et al., 2011), students' prior exposure to active learning helps them to engage with active learning activities, and they need more structure in order to best engage (Freeman et al., 2007). The competitive nature of most secondary education in the US has led to students devaluing self-guided learning, and any student who is enrolled in a course simply to get a grade will not respond well to being required to engage more deeply in concepts (Knight & Wood, 2005).

Limitations

The educational intervention on which the lab activity used in this study is based was designed by researchers in, and has so far only been implemented in, European Union (EU) nations. Despite American education systems' basis upon European systems, European institutions of higher education are more receptive to change in their methods of instruction and student development (Gapinski, 2010; Gaston, 2012, p. 61-64) European students learn more in secondary school than their counterparts in the United States (Bishop, 2010), and, as evidenced by EU support for the development of I SEE curriculum, novel methods of active learning are encouraged in European institutions at a higher rate than in the US (van Dyke, 2014). As such, the American population studied here likely came into the I SEE-style activity with very different expectations and preconceptions than did the European populations on which the I SEE curriculum was developed.

The I SEE modules already designed by Fantini et al. (2019) cover climate change, quantum computing, artificial intelligence, and carbon sequestration. So far, no I SEE modules have been designed to address antimicrobial resistance. For this reason, I had to create an entirely new module, rather than using one created by established researchers in the field. I SEE modules have also only been utilized in 16-19 year old students, and never at the university level, and typically are undertaken over a few sequential days with guided instruction. The weekly nature of the lab used in this study made it necessary to design a new module significantly different from the established I SEE modules, cutting out guided instruction in some of its intermediary portions.

The tool used in this study has not been tested or validated in other populations, and so we cannot be sure that conclusions drawn from data collected through the use of the RAUEQ can be generalized to other populations. As a multiple-choice tool, it forces students to select either a misconception or a scientific concept—this does not necessarily demonstrate that a student possesses or lacks relevant knowledge, as the majority of students' misconceptions are made up of both accurate and inaccurate elements (Nehm & Schonfeld, 2010). Including a free-response rationale question after each multiple-choice item helped us to ascertain which students truly held misconceptions, but this was not reflected in quantitative analysis of percent correct responses on the surveys. Likewise, by using a pre- and post-lab questionnaire tool to collect data about student knowledge, we limited the accuracy of our conclusions, as questionnaires provide only "snapshots" of participants' thoughts and feelings—not necessarily "durable" information (Richardson, 1994). Using *t* tests, too, to determine significance of students' gains in understanding overlooks the fact that those students who score low on a pre-test have more to gain than those who score similarly on both a pre- and post-test (Theobald & Freeman, 2014). However, using a more "accurate" method of assessment, such as normalized gain scores as described by Hake (1998), were impossible due to our relatively small sample sizes.

Data collection presented some difficulty in this population of students. While all students were enrolled in the same lab course, there were fifteen different sections taught by several different IAs, all of whom, despite training and guidance, certainly presented the lab activities with their own preconceptions and pedagogies. There was no attempt to control for these differences, and IAs were not supervised in how they presented material. Some may not have guided their students as effectively as others, and some of the students' misconceptions may have originated with these IAs, who are largely under-trained undergraduate students with little experience in teaching and often use techniques such as personification and false equivalency in order to attempt to connect students with difficult scientific concepts (*pers. obs.*).

Finally, introducing a single active learning activity in the midst of more traditional instruction may have confused students and increased their dissatisfaction with the activity. When introducing activities requiring critical thinking and collaboration with peers, students require a more gradual approach, with a large amount of guidance from instructors. Because students had not been expected to think critically to the extent they were during the assignment, students' focus on "correctness" rather than quality of thinking may have held them back from feeling satisfied with their performance on the I SEE-style activity (Miller & Malcolm, 1990). In future, in order to enhance students' participation in the activity, more active learning attitudes (open-mindedness, truth-seeking, curiosity, and self-confidence) must be worked into the rest of the lab curriculum (Colucciello, 1997).

Recommendations for Future Research

While several studies have been undertaken into nursing and pre-nursing students' understanding of broader biological concepts such as natural selection and evolution, few have focused more closely on antibiotic resistance as an example—and even fewer have attempted to engage these students with their role in the global antibiotic resistance crisis. This study attempts to offer a solution to students' deficiencies in understanding antibiotic resistance, as well as pre-nursing students' other deficiencies in collaboration with their peers, using creative thinking, and engaging in planning for the future.

Further research should identify other relevant concepts in the microbiology laboratory that could benefit from more active approaches to instruction in order to enhance students' knowledge about infection control and antibiotic stewardship.

A refined version of the I SEE-style lab activity could be tested in similar populations, using stricter guidelines so that students feel less lost in their approach to the assignment. Also, this activity could be evaluated as part of a more student-centered microbiology lab curriculum, in which multiple active learning activities are used.

Concluding Remarks

By creating a scenario planning-based activity to engage pre-nursing students in learning about antibiotic resistance, we were able to explore using active learning strategies to present socioscientific issues to students in a collaborative environment, adding to the hands-on experiences laboratory courses already bring.

While no significant improvements appeared in students' understanding of infection control, antibiotic resistance, and antibiotic stewardship, we were able to gather valuable data about students' knowledge and misconceptions that can help us shape future microbiology curriculum for pre-nursing students. We learned valuable lessons about what is required in order to encourage critical thinking and reflexivity in the pre-nursing microbiology lab curriculum, and about what students want to learn from the course. We can use what we have learned to improve our lab curriculum and pursue further studies about how best to introduce pre-nursing students to more complex assignments that require them to push the boundaries of not only their science knowledge, but their scientific thinking.

APPENDIX SECTION

APPENDIX A

Responsible Use of Antibiotics Electronic Questionnaire (RAUEQ)

Demographic Information

1. What is your gender?
    a. Female
    b. Male
    c. Other/not listed: ______________________________
2. What race(s) do you most closely identify with?
    a. American Indian/Alaska Native
    b. Asian
    c. Black/African-American
    d. Hispanic or Latinx
    e. Native Hawaiian/Other Pacific Islander
    f. White
    g. Other/not listed: ______________________________
3. What is your major?
    a. Pre-nursing
    b. Nutrition
    c. Respiratory Care
    d. Other/not listed: ______________________________
4. What is your classification?
    a. Freshman
    b. Sophomore
    c. Junior
    d. Senior
    e. Other/not listed: ______________________________
5. What is your age? ________________ years

Survey

For the following questions, select the single answer choice you believe to be the most correct. In the space below each question, explain why you made the selection you made in the question above.

1. When should one remove disposable gloves in a clinical setting?
    a. Only after coming into contact with any bodily fluids.
    b. Only between coming into contact with different patients.
    c. Only when hands need ot be washed.
    d. All of the above are correct.

Explain.

2. Which of the following is as effective as cleaning one's hands with soap and running water?
    a. Using hand sanitizer with 70% alcohol content.
    b. Using moist towelettes with 70% alcohol content.
    c. Washing one's hands with running water but no soap.
    d. None of the above are as effective as cleaning one's hands with soap and running water.

Explain.

3. Which of the following is most effective in preventing droplet transmission of disease?
    a. Wearing a plastic face shield.
    b. Covering a cough with one's hand or elbow.
    c. Wearing a disposable or washable mask which covers the nose and mouth.
    d. Maintaining a distance of three feet or more between individuals.

Explain.

4. Is antibiotic resistance an example of evolution?
    a. Yes
    b. No
    c. I don't know

Explain.

5. How do mutations which can lead to antibiotic resistance happen in bacteria?
    a. In response to the presence of an antibiotic.
    b. As a result of random chance.
    c. As a result of cell-to-cell communication in bacteria (quorum sensing).
    d. All of the above can lead to mutations in bacteria which can confer antibiotic resistance.

Explain.

6. When should a patient be given antibiotics?
    a. As a precaution if they may be exposed to a bacterial or viral infection.
    b. When they are exposed to a bacterial or viral infection.
    c. When they are diagnosed with a bacterial infection.
    d. All of the above are appropriate reasons to prescribe an antibiotic to a patient.

Explain.

7. When should a patient stop taking antibiotics that are prescribed to them?

a. When their prescription runs out or they are instructed to stop by their prescriber.
b. When the patient begins to feel better.
c. When the patient's symptoms begin to worsen.
d. All of the above are appropriate reasons for a patient to stop taking an antibiotic.

Explain.

8. When a bacterial infection is suspected, what is a prescriber's ideal course of action?
    a. Wait until the exact cause of infection is identified before starting a narrow-spectrum antibiotic treatment.
    b. Immediately begin treatment with a broad-spectrum antibiotic.
    c. Either of the above are appropriate courses of action.

Explain.

9. Which of the following can contribute to a rise in antibiotic resistance?
    a. Antibiotics in wastewater.
    b. Antibiotic use in livestock.
    c. Inappropriate antibiotics prescribing practices.
    d. All of the above can contribute to a rise in antibiotic resistance.

Explain.

10. Should a patient take the same antibiotic more than once?
    a. Yes, only as long as they do not show sensitivity to the antibiotic.
    b. Yes, only if they contract the same infection more than once.
    c. No, their body may become resistant to the antibiotic on a second exposure.
    d. No, developing the same infection more than once shows the first antibiotic did not work.

Explain.

11. Which of these is the only effective treatment for bacterial infection?
    a. A prescribed course of antibiotics.
    b. Medication to treat symtpoms until the infection resolves itself.
    c. New treatments such as phage therapy and quorum sensing inhibitors.
    d. All of the above may be used to effectively treat bacterial infections.

Explain.

Post-activity Evaluation

1. What previous knowledge do you have about antibiotic resistance?
    a. I have no prior knowledge about antibiotic resistance.
    b. I have read/heard a little bit about antibiotic resistance.

c. I have read/learned about antibiotic resistance in other biology classes.
d. I have read/learned a lot about antibiotic resistance and consider myself very familiar with it.

2. How comfortable would you feel explaining how antibiotic resistance arises?
    a. Not very comfortable
    b. Comfortable
    c. Very comfortable

To what extent did this lab activity help you to develop your understanding of the following topics:

3. How antibiotic resistance arises
    a. I still don't understand this
    b. I feel I understand this adequately
    c. I can explain this well
    d. I feel I know a great deal about this and can explain it well
4. Appropriate use of antibiotics in healthcare
    a. I still don't understand this
    b. I feel I understand this adequately
    c. I can explain this well
    d. I feel I know a great deal about this and can explain it well
5. Efforts to slow/stop the occurrence of antibiotic resistance
    a. I still don't understand this
    b. I feel I understand this adequately
    c. I can explain this well
    d. I feel I know a great deal about this and can explain it well.

For the topics above that you rated with either answer choice C or D, explain how the lab activity helped you to understand these topics better:

For the topics above that you rated with either answer choice A or B, explain how the activity could be improved to enhance your knowledge on the subject(s):

6. Do you feel this lab activity helped you to better articulate and present a strategy to solve a problem?
    a. Not at all
    b. I am still uncomfortable with this
    c. I am a little more comfortable with this
    d. I feel significantly more comfortable presenting solutions than I was before

Explain why you chose the answer you chose above:

7. How would you rate your overall experience of this lab activity?
    a. I did not find it valuable or helpful
    b. I found it helpful, but not necessarily with the course material
    c. I thought it was interesting, but not helpful
    d. I thought it was interesting and that it helped me to engage with the course material

Explain why you chose the answer you chose above.

8. To what extent do you think your experience with this lab activity will help you in your future career?
    a. This will not help me in my future career
    b. This may help with some aspect of my future career
    c. This will make me better equipped for my future career
    d. This will give me critical skills for my future career

Explain why you chose the answer you chose above.

APPENDIX B
I SEE-STYLE LAB ACTIVITY HANDOUT AND RUBRIC
Solving Antibiotic Resistance Through Scenario Planning

BIO 2440: Principles of Microbiology

Antibiotic resistance is expected to rise over the next several years, creating a massive global healthcare crisis.[1] Rates of treatment failure and patient fatalities are significantly higher in resistant infections (such as MRSA) than in non-resistant infections. Infection with resistant strains also increases the incidence of complications, such as the development of infertility due to STIs.[2]

Today, your assignment is to plan a better future for healthcare by researching current problems in order to think of solutions. You will design an ideal future—whatever outcome you think is ideal—then back-track to today to set the plants for that future into effect.

Step One: Review the Literature.

Before lab, you will be given two articles. The first article, 'The Antibiotic Resistance Crisis' by C. Lee Ventola, details antibiotic resistance, its impacts on public health in general, and a few cases in which resistance has significantly affected treatment. This should help you to better understand the problem at hand.

The second article, 'Complexity and Health—Yesterday's Traditions, Tomorrow's Future' by Joachim P. Sturmberg and Carmel M. Martin, explains complexity science and its role in healthcare problem-solving. Complexity science includes the study of systems and urges people to think in non-linear, network-based ways about problems and the way those problems can interact. Studies show that scientists and healthcare professionals can be more effective problem-solvers if they make an effort to understand systems rather than taking a reductionist approach, in which problems are reduced to smaller components.[3] Consider a machine which is malfunctioning—you may take it apart to examine each part individually, or you my examine it as a system, knowing that certain parts are connected to many more parts than others, and thus more important to the machine's ability to work. Use your new understanding of complexity to complete this assignment.

Step Two: Examine the Future

On your lab Canvas site, find the assignment labelled 'Imagining a Resistance-Free Future.' Before class, submit a brief description of your ideal 2040. Consider the following:

- In 2040, what is healthcare like in regards to infectious disease?
- What are doctors, drug developers, epidemiologists, and other researchers doing to ensure this ideal future is achieved and maintained?

Your description of the ideal 2040 can be as specific as you feel necessary—just be sure to highlight what you think the state of infectious disease should be like.

At the beginning of lab, your IA will take all of your submitted futures and write them on the board. The class will narrow these futures down to just a few well-thought-out ideas by discussing how realistic each future is. Then, the class will break into groups of four and each group will select whichever future they like best.

Step Three: Use the Future to Plan the Present

You will work in groups with your selected futures in order to back-cast—this means planning what happens between now and 2040 to lead to this future. You can use whatever resources you feel are appropriate—use the Internet to search for relevant journal articles and news stories (and cite them in your notes), or re-read the assigned journal articles on Canvas, for example—and engage in discussion within your group. After 30 minutes, you should be prepared to present your plans to the rest of the lab.

Try to answer the following questions:

- What are your plans, in detail?

- What is your timeline for implementing these plans?
- What are some challenges in implementing these plans?
- Who are the stakeholders that would be involved in the success of these plans? Who is most impacted by the changes you have made?

Imagine your group is a team of scientists and healthcare providers in the year 2040. Take on the roles of the people who could be responsible for your plan. Each group will have five minutes to present to the class, and five minutes to answer questions from other students in the class. Refer to the attached rubric to plan your presentation.

1. Ventola, C. L. (2015). The antibiotic resistance crisis. *Pharmacy and Therapeutics, 40*(4), 277-283.
2. Friedman, N. D., Temkin, E., & Carmeli, Y. (2016). The negative impact of antibiotic resistance. *Clinical Microbiology and Infection, 22*(5), 416-422.
3. Miles, A. (2009). Complexity and healthcare: People and systems, theory and practice. *Journal of Evaluation in Clinical Practice, 15,* 409-410.

	Poor (0)	Moderate (1.5)	Good (2)	Excellent (2.5)
Timeline for implementing plan	No timeline given	Rough timeline (e.g. 'within ten years') given	Most elements of plan given deadlines for implementation, but deadlines are not necessarily logical	Each element of plan is given a deadline for implementation, and each deadline makes realistic sense for the amount of work required
Initial goals statement; acknowledgement of goals not met	Goal statement too broad (e.g. 'there is no antibiotic resistance')	Goals stated, but may not be realistic enough to achieve	Realistic goals states, summary given of goals that were not met	Realistic goals stated, summary given of how some goals were met and why some goals were not met
Roles required for implementation	No roles detailed	Roles of researchers presenting given	Roles stated focus mainly on the biomedical sector	Roles are detailed for the biomedical sector, public policy sector, education sector, and any other relevant stakeholders
Impact statement	No impact statement	Impact statement focuses on only the biomedical impact on the plan	Impact statement includes biomedical impact as well as secondary impacts (e.g. agricultural, environmental)	Impact statement takes all possible impacts of plan into consideration, whether obvious (biomedical) or not obvious (other sectors)

APPENDIX C
CONSENT FORM

Toni Mac Crossan, a graduate student at Texas State University, is conducting a research study to measure how a scenario planning-based learning intervention can help pre-nursing students understand antibiotic resistance. You are being asked to complete this survey because you are enrolled in BIO 2440: Principles of Microbiology.

Participation is voluntary. The survey will take approximately 30 minutes or less to complete. You must be at least 18 years old to take this survey.

This study involves no foreseeable serious risks. We ask that you try to answer all questions; however, if there are any items that make you uncomfortable or that you would prefer to skip, please leave the answer blank. Your responses are confidential.

Reasonable efforts will be made to keep the personal information in your research record private and confidential. Any identifiable information obtained in connection with this study will remain confidential and will be disclosed only with your permission or as required by law. The members of the research team and the Texas State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.

Your name will not be used in any written reports or publications which result from this research. Data will be kept for three years (per federal regulations) after the study is completed and then destroyed.

If you have any questions or concerns, feel free to contact Toni Mac Crossan or their faculty advisor:

Toni Mac Crossan, graduate student	Dr. Julie Westerlund, Associate Professor
Department of Biology	Department of Biology
(830) 837 2227	(512) 245 3361
acm138@txstate.edu	jw33@txstate.edu

This project #7399 was approved by the Texas State IRB on 16 September 2020. Pertinent questions or concerns about the research, research participants' rights, and/or research-related inquiries to participants should be directed to the IRB chair, Dr. Denise Gobert 512 716 2652 (dgobert@txstate.edu) or to Monica Gonzales, IRB Regulatory Manager 512 245 2334 (meg201@txstate.edu).

If you would prefer not to participate, please do not fill out a survey.

If you consent to participate, please complete the survey.

APPENDIX D
RECRUITMENT EMAIL

From: [Toni Mac Crossan, acm138@txstate.edu]

BCC: [BIO 2440 Students]

Subject: Research Participation Invitation in Online Scenario Planning Exercise to Learn About Antibiotic Resistance

This email message is an approved request for participation in research that has been approved by the Texas State Institutional Review Board (IRB).

Dear BIO 2440 Lab Student,

Hello! I am Toni Mac Crossan, a Biology graduate student at Texas State University.

I am conducting a research study to determine the effectiveness of an online scenario planning activity that can aid students in their understanding of how antibiotic resistance arises and how the crisis of antibiotic resistance can be addressed in the future. You are being asked to complete a survey concerning your understanding of antibiotic resistance and infection control because you are enrolled in a BIO 2440 lab section this semester.

The purpose of voluntary research participation in this project is to determine the effectiveness of an online activity in understanding antibiotic resistance. The value of the project is that, with input from students, an online scenario planning activity can be improved and be used in future BIO 2440 laboratory exercises that require remote learning for the safety of students. Once your survey data has been received, all identifiers will be removed so that your confidentiality will be maintained.

You have been selected to participate in the research since you are enrolled in a BIO 2440 lab. The anticipated time of participation is no more than 3 hours during our regularly scheduled class sessions. The participation is strictly voluntary. As an incentive for participating, you will be offered extra credit to go toward your lab Quiz 4. If you elect not to participate, then you will have access to a similar activity that will offer the same amount of extra credit toward the same assignment.

To participate in this research or to ask questions about this research please contact me, Toni Mac Crossan, at acm138@txstate.edu or by phone at XXX XXXX.

Thank you,

Toni Mac Crossan

This project #7399 was approved by the Texas State IRB on 16 September 2020. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Denise Gobert 512-716-2652 – (dgobert@txstate.edu) or to Monica Gonzales, IRB Regulatory Manager 512-245-2334 – (meg201@txstate.edu).

APPENDIX E
VERBAL INVITATION SCRIPT

Hi! I am Toni Mac Crossan, a Biology graduate student at Texas State University.

I am conducting a research study to determine the effectiveness of an online scenario planning activity that can aid students in their understanding of how antibiotic resistance arises and how the crisis of antibiotic resistance can be addressed in the future. You are being asked to complete a survey concerning your understanding of antibiotic resistance and infection control because you are enrolled in a BIO 2440 lab section this semester.

The purpose of voluntary research participation in this project is to determine the effectiveness of an online activity in understanding antibiotic resistance. The value of the project is that, with input from students, an online scenario planning activity can be improved and be used in future BIO 2440 laboratory exercises that require remote learning for the safety of students. Once your survey data has been received, all identifiers will be removed so that your confidentiality will be maintained.

You have been selected to participate in the research since you are enrolled in a BIO 2440 lab. The anticipated time of participation is no more than 3 hours during our regularly scheduled class sessions. The participation is strictly voluntary. As an incentive for participating, you will be offered extra credit to go toward your lab Quiz 4. If you elect not to participate, then you will have access to a similar activity that will offer the same amount of extra credit toward the same assignment.

To participate in this research or to ask questions about this research please contact me at acm138@txstate.edu or by phone at XXX XXXX.

Thank you for your time!

APPENDIX F
SECOND CYCLE CODEBOOK

Pattern codes: RAUEQ free-response rationales

Code	Definition	Includes	Excludes
Cleanliness	Students emphasize that something is sanitary or use language that refers to purity or freedom from disease.	Asepsis, washing hands (when not mentioned in question/answer choices)	Language used in questions/answer choices
Opinion	Students express some sort of personal preference(s).	Expressing preference for an answer choice that was not given, or a combination of choices	Mentions of personal experience; phrases indicating being unsure; phrases like "I think", "I guess"
Contamination	Students refer to contamination or cross-contamination directly or talk about bacteria being moved from one place to another.	Mentions of surfaces or other (non-person) items getting bacteria on them	Phrases mentioning transmission or "spread" of disease, language used in question/answer choices
Personification	Students ascribe feelings, desires, aspirations, or some other indicator of sentience to microbes.	Implying a bacterium or other microbe is doing something intentionally, using anthropomorphic language to describe microbes, comparing actions of microbes to those of humans	Describing normal bacterial functions using neutral language (e.g. "reproduce" or "replicate")
Heritability	Students clarify that a genetic change or gene is heritable or passed from one generation to another.	Describing natural selection as a process taking place over multiple generations, passing genetic material to "offspring"	Mentions of horizontal gene transfer (e.g. conjugation) or picking up extracellular DNA
Anthropocentrism	Students centre the actions of a particular person, or humans in general, or blame the actions of people for something.	Reducing complex events to only human contributions; mentioning actions or conditions as	Echoing language found in questions/ answer choices

		beneficial or detrimental to oneself or others; re-centering biological processes of other species in humans	
Authority	Students cite the teaching of a professor/lecturer, IA, government agency, paper they read, etc. as evidence for their answer.	Specific mentions of the course, an agency (e.g. the CDC), or another individual; more vague references to trusted outside sources (e.g. "it has been proven", "science shows"); implication that the advice of some "expert" agent (e.g. a doctor) is unquestionable	References to one's own knowledge, references to any person who could not be classified as "expert" (e.g. a parent, a friend); reference to personal experience
Precaution against disease	Students say precautions should be taken against the transmission or worsening of disease.	Talking about taking measures against the spread of specific diseases (e.g. COVID-19); referencing "relapse" of a disease; mentions of risk for contracting disease	Language used in questions/answer choices (e.g. "droplet transmission" in Question 3)
Precaution against resistance	Students say precautions should be taken against exposing microbes to unnecessary selective pressures that could increase incidence of antibiotic resistance.	Mentioning that an answer choice is not viable due to potential for selective pressure; direct reference to selective pressure or unnecessary exposure of microbes to drugs	Language used in questions/answer choices
Personal experience	Students cite some experience from their own lives to back up their answer choice.	Mentions of a job, mentions of experience during disease or medical care, "when I…" or "I always…"	Mentions of experiences in the classroom or experience with an instructor or text

Foundational learning	Students connect concepts in the survey to other concepts learned in the course (outside of the assigned reading material for the antibiotics lab) or other biology curriculum.	Any concept not specifically covered in the lab material or survey (e.g. evolution, mutation), explanations of basic biological processes; explanations of differences between groups of microbes (e.g. between bacteria and viruses)	References to other parts of the survey or to concepts in the lab materials; language used in questions/answer choices
Unsure	Students say explicitly that they do not know an answer, or use noticeably hesitant language.	Phrases like "I don't know", "I'm not sure"; using question marks; admissions that the student is guessing the answer	Conversational cues like "I think" or "I believe" that may be part of the student's normal speaking pattern (hedging language[1])
It depends	Students emphasize that the correctness of their answer would depend on certain circumstances not explicitly defined in a given scenario.	Many phrases beginning with "if", "depending on", or "it depends"; specifying that there are exceptions to a given "rule"	Phrases specifically and concretely mentioning patient care considerations or precautions against spreading disease or resistance
Emphasis on patient care	Students emphasise the quality of care a patient receives.	Referring to the comfort of a patient; specifying that a choice is integral to protecting a patient from suffering in some way	Phrases that, while they mention a patient or patient care, do not focus on the wellbeing of a patient
Speed	Students emphasize the speed at which a patient can be treated or an infection can be resolved.	Placing a higher value on the speed or efficiency of a treatment than the patient's comfort or the risk of spreading disease or antibiotic-resistant organisms	Language used in the question/ answer choices
Present versus future	Students compare current conditions or available treatments and how they work (or their efficacy) to	Explanations that the future will be different; specifying that something	Language used in question/answer choices; comparing the present to the

	future conditions or available treatments.	which is a problem now will not be a problem in the future, or vice versa; classifying something as inappropriate for the sole reason of being "not ready yet" or "not well-studied"	past; explaining a current condition or available treatment without comparing it to a future condition
Protect	Students use language which emphasizes that aseptic techniques or related precautions protect the user from some harm.	Broader descriptions of something as being beneficial for the user or the general population	Language which centers the treatment or well-being of a particular patient
COVID-19	Students talk about the COVID-19 pandemic.	Mentions of COVID-19 or its causative agent (SARS-CoV-2) by name; vaguer references to "the pandemic" or "what's going on now"; mentions of changes that have taken place in direct response to this pandemic	Direct descriptions of the actions of some authority figure or agency (e.g. the CDC) without connection to the pandemic
Body is resistant	Students describe resistance to antibiotics as something that happens in human bodies or human cells/systems	Descriptions of a person as being resistant to antibiotics; mention of resistance as something that is passed from a person to their offspring	Comparisons of bacteria to people in ways that personify bacteria; language which inappropriately centers human experience(s)

1. "Hedging language" refers to a form of linguistic politeness in which statements are presented as opinions rather than facts in order to "soften" one's language, and, rather than demonstrating uncertainty, hedging may indicate more sophisticated epistemological beliefs about the nature of science (Livytska, 2019; Peffer & Kyle; 2017). Because it appears that the use of hedging language generally indicates sureness, rather than unsureness, it was not included in this code.

Pattern codes: post-lab evaluation free-response items

Code	Definition	Includes	Excludes
Active learning	Students mention some component of active learning (e.g., group discussion or flipped classroom).	Specific mentions of student-centered instruction, creativity, or "teaching to learn"	Negative experiences with active learning techniques; mentions of lacking concrete guidance
Repetition	Students talk about information being presented more than once, either within the lab or activity or between the lab and other courses.	Mentions of information appearing in both lab and lecture sections of the course, or in previous courses	New information being added to information a student has already learned
Engagement with content	Students talk about enjoying or feeling connected with the content through the lab activity.	Appreciation of "hands-on" learning or use of visuals that allow more direct engagement with concepts	Neutral language about the way the content is presented
Stewardship	Students talk about engaging in stewardship activities in their future workplaces.	Talking about being sure antibiotics are necessary, reviewing prescriptions, or monitoring the length of antibiotic therapy	Talking about personal experiences with taking antibiotics or talking to friends or family about antibiotics
Patient education	Students mention being responsible for educating patients about disease and antibiotic use in their future roles as nurses.	Mentioning that in the future, in the student's career as a nurse, they will need to deliver information to patients	Mentioning talking to friends and/or family about antibiotic use or resistance
COVID-19	Students mention the COVID-19 pandemic or the way it has affected course modality.	Talking about COVID-19 or its causative agent (SARS-CoV-2); talking about having to take the lab online or in staggered groups due to precautions against COVID-19	Negative experiences with course design not specifically related to changes in modality due to COVID-19

Independent research	Students talk about readings they did on their own in addition to the assigned readings.	Having to find outside sources for assignments; having to read papers in library databases	Experiences with the assigned readings for the lab activity
Students' responsibility	Students take responsibility for their own learning.	Taking blame for not having studies or read materials thoroughly; explaining that students must meet instructors halfway	Feelings of inadequate guidance form an instructor; excuses about not knowing or learning something
Bad group experience	Students report negative experiences with group members or delegation of work within a group.	Feelings of frustration with group work in this lab activity or in general, "I have to do all the work"; lacking communication with group members	Positive feelings about engaging with one's peers
Lacking skills	Students complain that they do not have certain skills.	Explicit statements about not having certain skills related to problem solving, research, or presentation	Statements about lacking knowledge about specific concepts, or lacking guidance
Lacking instruction	Students complain that they did not have enough guidance or information from their instructors.	Not feeling confident that they understand the instructions or the way in which their work was evaluated, requiring more oversight from an instructor	Taking responsibility for not engaging with the lab activity to the best of their ability
Learning from lab	Students directly mention something they learned from the lab activity.	Explaining what they learned from the lab or the research they did in order to complete the lab activity	Mentions of things learned from lecture, other courses, or anywhere else outside of lab or completing the lab activity

New information	Students describe information as being new to them, but part of larger concepts.	Talking about how information from the lab activity built upon or "fleshed out" concepts they had been introduced to previously	Building knowledge completely anew, as in "starting from scratch"
Starting from scratch	Students describe learning about antibiotics/resistance as something they had never heard of or learned about before.	Saying that the lab activity "raised awareness" about antibiotic resistance, feeling surprise or interest in not having heard about issues relating to antibiotic use and/or resistance before	Talking about new information that built upon information they had already learned

REFERENCES

Abbo, L., Sinkowitz-Cochran, R., Smith, L., Ariza-Heredia, E., Gómez-Marín, O., Srinivasan, A., & Hooton, T. M. (2011). Faculty and resident physicians' attitudes, perceptions, and knowledge about antimicrobial use and resistance. *Infection Control and Hospital Epidemiology, 32*(7), 714-718.

Abraham, J. K., Meir, E., Perry, J., Herron, J. C., Maruca, S., & Stal, D. (2009). Addressing undergraduate student misconceptions about natural selection with an interactive simulated laboratory. *Evolution: Education and Outreach, 2,* 393-404.

Agre, V. & Thomas, K. T. (2018). A study to assess effectiveness of teaching methods on retention of knowledge among nursing students of Pune City. *International Journal of Science and Research, 5*(6), 713-718.

Ahouah, M., Lartigue, C., & Rothan-Tondeur, M. (2019). Perceptions of antibiotic therapy among nursing home residents: Perspectives of caregivers and residents in a mixed exploratory study. *Antibiotics, 8,* 66-78.

Akbar, Z., Alquwez, N., Alsolais, A., Thaaha, S. K., Ahmad, M. D., & Cruz, J. P. (2021). Knowledge about antibiotics and antibiotic resistance among health-related students in a Saudi university. *Journal of Infection in Developing Countries, 15*(7), 925-933.

Akpan, M. R., Ahmad, R., Shebl, N. A., & Ashiru-Oredope, D. (2016). A review of quality measures for assessing the impact of antimicrobial stewardship programs in hospitals. *Antibiotics, 5*(1), 5.

Aloufi, M. A., Jardin, R. J., Gerdtz, M. F., & Kapp, S. (2021). Reducing stress, anxiety and depression in undergraduate nursing students: Systematic review. *Nurse Education Today, 102*, 104877.

Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures, 46*, 23-40.

American Association of Colleges of Nursing. (2008). *The essentials of baccalaureate education for professional nursing practice.* aacn.nche.edu/education/pdf/BaccEssentials08.pdf.

Aminov, R. I. (2009). The role of antibiotics and antibiotic resistance in nature. *Environmental Microbiology, 11*(12), 2970-2988.

Anderson, J. L., Warren, C. A., Perez, E., Louis, R. I., Phillips, S., Wheeler, J., Cole, M., & Misra, R. (2008). Gender and ethnic differences in hand hygiene practices among college students. *American Journal of Infection Control, 36*(5), 361-368.

Andrews, T. M., Leonard M. J., Colgrove, C. A., & Kalinowski, S. T. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE – Life Sciences Education, 10,* 394-405.

Angheloiu, C., Chaudhuri, G., & Sheldrick, L. (2017). Future tense: Alternative futures as a design method for sustainability transitions. *The Design Journal, 20*(S1), S3213-S3225.

Arnold, S. A. & Straus, S. E. (2009). Interventions to improve antibiotic prescribing practices in ambulatory care. *Cochrane Database of Systematic Reviews, 4*, n.p.

Association of American Colleges and Universities. (2015). *Liberal education outcomes: A preliminary report on student achievement in college*. Washington.

Auerbach, A. J., Higgins, M., Brickman, P., & Andrews, T. C. (2018). Teacher knowledge for active-learning instruction: Expert-novice comparison reveals differences. *CBE – Life Sciences Education, 17*(1), ar12.

Ayub, A., Goyal, A., Kotwal, A., Kulkarni, A., Kotwal, A., & Mahen, A. (2013). Infection control practices in health care: Teaching and learning requirements of medical undergraduates. *Medical Journal Armed Forces India, 69*, 107-112.

Barata Tavares, A., Viegas, S., & Sousa-Uva, A. (2019). Public health and climate change: Do we need a more proactive approach? *Portuguese Journal of Public Health, 37*(2-3), 55-56.

Barelli, E. (2017). *Science of complex systems and future-scaffolding skills: A pilot study with secondary school students.* [Master's thesis, University of Bologna]. AMS Laurea Institutional Theses Repository. amslaurea.unibo.it/13644/1/EB_Tesi_solotesto.pdf.

Baron, K. A. (2017). Changing to concept-based curricula: The process for nurse educators. *The Open Nursing Journal, 11,* 277-287.

Bibri, S. E. (2018). Backcasting in futures studies: A synthesized scholarly and planning approach to strategic smart sustainable city development. *European Journal of Futures Research, 6,* ar13.

Bishop, B. & Anderson, C. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27*, 415-427.

Bishop, J. H. (2010). *Which secondary education systems work best? The United States or northern Europe.* Cornell University, ILR School. digitalcommons.ilr.edu/workingpapers/105.

Botta, R. A., Dunker, K., Fenson-Hood, K., Maltarich, S., & McDonald, L. (2008). Using a relevant threat, EPPM and interpersonal communication to change hand-washing behaviours on campus. *Journal of Communication in Healthcare, 1*(4), 373-381.

Bouhalleb, A. & Smida, A. (2020). Exploring the relationship between scenario planning and strategic flexibility and complexity. *European Journal of International Management, 14*(3), n. p.

Bowden, J. (2021, March 14). Fauci: CDC studying data suggesting 3 feet of social distancing 'OK under certain circumstances'. *The Hill.* thehill.com/homenews/Sunday-talk-shows/543147-fauci-cdc-aware-of-data-suggesting-3-feet-of-social-distancing-ok.

Boychuck Duchscher, J. E. (1999). Catching the wave: Understanding the concept of critical thinking. *Journal of Advanced Nursing, 29*(3), 577-583.

Branchetti, L., Cutler, M., Laherto, A., Levrini, O., Palmgren, E. K., Tasquier, G., & Wilson, C. (2018). The I SEE Project: An approach to futurize STEM education. *Visions for Sustainability, 9,* 10-26.

Briggs, A. G., Hughes, L. E., Brennan, R. E., Buchner, J., Horak, R. E. A., Amburn, D. S. K., McDonald, A. H., Primm, T. P., Smith, A. C., Stevens, A. M., Yung, S. B., & Paustian, T. D. (2017). Concept inventory development reveals common student misconceptions about microbiology. *Journal of Microbiology and Biology Education, 18*(3), 1-9.

Brock, D., abu Rish, E., Chiu, C., Hammer, D., Wilson, S., Vorvick, L., Blondon, K., Schadd, D., Liner, D., & Zierler, B. (2013). Interprofessional education in team communication: Working together to improve patient safety. *BMJ Quality and Safety in Health Care, 22,* 414-423.

Brussow, J. A., Roberts, K., Scaruto, M., Sommer, S., & Mills, C. (2019). Concept-based curricula: A national study of critical concepts. *Nurse Educator, 44*(1), 15-19.

Bryman, A. (2006). Integrative quantitative and qualitative research: How is it done? *Qualitative Research, 6*(1), 97-113.

Bull, K. S., Montgomery, D., & Baloche, L. (1995). Teaching creativity at the college level: A synthesis of curricular components perceived as important by instructors. *Creativity Research Journal, 8*(1), 83-89.

Burnham, J. P. (2021). Climate change and antibiotic resistance: A deadly combination. *Therapeutic Advances in Infectious Disease, 8,* 1-7.

Burt, G. & van der Heijden, K. (2003). First steps: Towards purposeful activities in scenario thinking and future studies. *Futures, 35*(10, 1011-1026.

Caena, F. (2014). Comparative glocal perspectives on European teacher education. *European Journal of Teacher Education, 37*(1), 106-122.

Caldwell, R. & Cochran, C. (2018). Infusing social justice in undergraduate nursing education: Fostering praxis through simulation. *Journal of Forensic Nursing, 14*(2), 88-97.

Carter, R. R., Sun, J., & Jump, R. L. P. (2016). A survey and analysis of the American public's perceptions and knowledge about antibiotic resistance. *Open Forum Infectious Diseases, 3*(3).

Casadevall, A., Kontoyiannis, D. P., & Robert, V. (2019). On the emergence of *Candida auris*: Climate change, azoles, swamps, and birds. *mBio, 10*(4), e01397-19.

Centers for Disease Control and Prevention. (2017). Redefining the antibiotic stewardship team: Recommendations from the American Nurses' Association/Centers for Disease Control and Prevention workgroup on the role of registered nurses in hospital antibiotic stewardship practices. https://www.cdc.gov/antibiotic-use/healthcare/pdfs/ANA-CDC-whitepaper.pdf

Centers for Disease Control and Prevention. (2019). Antibiotic resistance threats in the United States, 2019. https://www.cdc.gov/drugresistance/pdf/threats-report/2019-ar-threats-report-508.pdf

Centers for Disease Control and Prevention. (2020, September 10). *When & How to Use Hand Sanitizer*. https://www.cdc.gov/handwashing/show-me-the-science-hand-sanitizer.html.

Centers for Disease Control and Prevention. (2021a, July 19). *Antibiotic Prescribing and Use: Educational Resources for Healthcare Professionals*. https://www.cdc.gov/antibiotic-use/training/materials.html.

Centers for Disease Control and Prevention. (2021b, March 24). *Antibiotic Prescribing and Use: Patient Education and Promotional Resources*. https://www.cdc.gov/antibiotic-use/materials-references/index.html.

Chan, R., Molassiotis, A., Chan, E., Chan, V., Ho, B., Lai, C., Lam, P., Shit, F., & Yiu, I. (2002). Nurses' knowledge of and compliance with universal precautions in an acute care hospital. *International Journal of Nursing Studies, 39*(2), 157-163.

Chan, Z. C. Y., Cheng, W. Y., Fong, M. K., Fung, Y. S., Ki, Y. M., Li, Y. L., Wong, H. T., Wong, T. L., & Tsoi, W. F. (2019). Curriculum design and attrition among undergraduate nursing students: A systematic review. *Nurse Education Today, 74,* 41-53.

Charani, E., Cooke, J., & Holmes, A. (2010). Antibiotic stewardship programmes—what's missing? *Journal of Antimicrobial Chemotherapy, 65*, 2275-2277.

Charani, E., Castro-Sanchez, E., Sebdalis, N., Kyratsis, Y., Drumright, L., Shah, N., & Holmes, A. (2013). Understanding the determinants of antimicrobial prescribing within hospitals: The role of "prescribing etiquette." *Clinical Infectious Diseases, 57*(2), 188-196.

Chermack, T. J. (2004). Improving decision-making with scenario planning. *Futures, 36,* 295-309.

Chicca, J. & Shellenbarger, T. (2018). Connecting with Generation Z: Approaches in nursing education. *Teaching and Learning in Nursing, 13,* 180-184.

Chokshi, A., Sifri, Z., Cennimo, D., & Horng, H. (2019). Global contributors to antibiotic resistance. *Journal of Global Infectious Diseases, 11*(1), 36-42.

Chong, K. L., Ng, C. S., Hori, N., Yang, R., Verzicco, R., & Lohse, D. (2021). Extended lifetime of respiratory droplets in a turbulent vapor puff and its implications on airborne disease transmission. *Physical Review Letters, 126,* 034502.

Clancy, J., McVicar, A., & Bird, D. (2000). Getting it right? An exploration of issues relating to the biological science in nurse education and nursing practice. *Journal of Advanced Nursing, 32*(2), 1522-1532.

Cleveland, L. M., Olimpo, J. T., & DeChenne-Peters, S. (2017). Investigating the relationship between instructors' use of active learning strategies and students' conceptual understanding and affective changes in introductory biology: A comparison of two active-learning environments. *CBE – Life Sciences Education, 16*(2).

Cloud-Hansen, K. A., Kuehner, J. N., Tong, L., Miller, S., & Handelsman, J. (2008). Money, sex, and drugs: A case study to teach the genetics of antibiotic resistance. *CBE – Life Sciences Education, 7,* 302-309.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*, 37-46.

Coley, J. D. & Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE – Life Sciences Education, 14,* 1-19.

Colgan, R. & Powers, J. H. (2001). Appropriate antimicrobial prescribing: Approaches that limit antibiotic resistance. *American Family Physician, 64*(6), 999-1005.

Colucciello, M. L. (1997). Critical thinking skills and dispositions of baccalaureate nursing students—A conceptual model for evaluation. *Journal of Professional Nursing, 13*(4), 236-245.

Courtenay, M., Castro-Sanchez, E., Gallagher, R., McEwen, J., Bulabula, A. N. H., Carre, Y., du Toit, B., Figueiredo, R. M., Gjerde, M. E., Hamilton, N., Jorgoni, L., Ness, V., Olans, R., Padoveze, M. C., Rout, J., van Gulik, N., & van Zyl, Y. (2019). Development of consensus-based international antimicrobial stewardship competencies for undergraduate nurse education. *Journal of Hospital Infection, 103*(3), 244-250.

Courtenay, M., Burnett, E., Castro-Sánchez, E., du Toit, B., Figueiredo, R. M., Gallagher, R., Gotterson, F., Kennedy, H., Manias, E., McEwen, J., Ness, V., Olans, R., & Padoveze, M. C. (2020). Preparing nurses for COVID-19 response efforts through involvement in antimicrobial stewardship programmes. *Journal of Hospital Infection, 106*(1), 176-178.

Cox, J. L. & Simpson, M. D. (2018). Microbiology education and infection control competency: Offering a new perspective. *Journal of Microbiology and Biology Education, 19*(2), 1-6.

Craft, J., Hudson, P., Penderleith, M., Wirihana, L., & Gordon, C. (2013). Commencing nursing students' perceptions and anxiety of bioscience. *Nurse Education Today, 33,* 1399-1405.

Crowe, A., Dirks, C., & Wenderoth, M. P. (2008). Biology in Bloom: Implementing Bloom's taxonomy to enhance student learning in biology. *CBE – Life Sciences Education, 7,* 368-381.

Davey, P. & Garner, S. (2007). Professional education on antimicrobial prescribing: A report from the Specialist Advisory Committee on Antimicrobial Resistance (SACAR) Professional Education Subgroup. *Journal of Antimicrobial Chemotherapy, 60*(S1), i27-i32.

Davies, J. & Davies, D. (2010). Origins and evolution of antibiotic resistance. *Microbiology and Molecular Biology Reviews, 74*(3), 417-433.

de Swardt, H. C., van Rensburg, G. H., & Oosthuizen, M. (2017). Supporting students in professional socialization: Guidelines for professional nurses and educators. *International Journal of Africa Nursing Sciences, 6,* 1-22.

Dempsey, P. P., Businger, A. C., Whaley, L. E., Gagne, J. J., & Linder, J. A. (2014). Primary care clinicians' perceptions about antibiotic prescribing for acute bronchitis: A qualitative study. *BMC Family Practice, 15*, 194.

Derreth, R. T. & Wear, M. P. (2021). Critical online service-learning pedagogy: Justice in science education. *Journal of Microbiology and Biology Education, 22*(1), ar61.

Doron, S. & Davidson, L. E. (2011). Antimicrobial stewardship. *Mayo Clinic Proceedings, 86*(11), 1113-1123.

Dyar, O. J., Beović, B., Vlahović-Palčevski, V., Verheij, T., & Pulcini, C. (2016). How can we improve antibiotic prescribing in primary care? *Expert Review of Anti-Infective Therapy, 14*(4), 403-413.

Eberlein, T., Kampmeier, J., Minderhout, V., Moog, R. S., Platt, T., Varma-Nelson, P., & White, H. B. (2008). Pedagogies of engagement in science. *Biochemistry & Molecular Biology Education, 36*(4), 262-273.

Edgar, T., Boyd, S. D., & Palamé, M. J. (2009). Sustainability for behaviour change in the fight against antibiotic resistance: A social marketing framework. *Journal of Antimicrobial Chemotherapy, 63*, 230-237.

Edwards, R., Drumright, L., Kiernan, M., & Holmes, A. (2011). Covering more territory to fight resistance: Considering nurses' role in antimicrobial stewardship. *Journal of Infection Prevention, 12*(1), 6-10.

Fantini, P., Branchetti, L., Cutler, M., Laherto, A., Levrini, O., Palmgren, E. K., Tasquier, G., & Wilson, C. (2019). 03 – I SEE Module Guide.

Fernandes, M., Thakur, J. R., & Gavanje, M. S. (2021). A study to assess knowledge regarding COVID-19 among nursing students. *Asian Journal of Nursing Education and Research, 11*(1), 65-67.

Ferrari, M. & Chi, M. T. H. (1998). The nature of naïve explanations of natural selection. *International Journal of Science Education, 20*(10), 1231-1256.

Fishman, N. (2006). Antimicrobial stewardship. *American Journal of Medicine, 119*(6 Suppl 1), S53-S61.

Fleming-Dutra, K. E., Hersh, A. L., Shapiro, D. J., Bartoces, M., Enns, E. A., File, T. M., Finkelstein, J. A., Gerber, J. S., Hyun, D. Y., Linder, J. A., Lynfield, R., Margolis, D. J., May, L. S., Merenstein, D., Metlay, J. P., Newland, J. G., Piccirillo, J. F., Roberts, R. M., Sanchez, G. V., Suda, K. J., Thomas, A., Woo, T. M., Zetts, R. M., & Hicks, L. A. (2016). Prevalence of inappropriate antibiotic prescriptions among US ambulatory care visits, 2010-2011. *JAMA, 315*(17), 1864-1873.

Fluent, M. T., Jacobsen, P. L., & Hicks, L. A. (2016). Consideration for responsible antibiotic use in dentistry. *The journal of the American Dental Association, 147*(8), 683-686.

Flynn, L., Liang, Y., Dickson, G. L., Xie, M., & Suh, D. (2012). Nurses' practice environments, error interception practices, and inpatient medication errors. *Journal of Nursing Scholarship, 44*(2), 180-186.

Fraher, E., Spetz, J., & Naylor, M. (2015). Nursing in a transformed health care system: New roles, new rules. *Interdisciplinary Nursing Quality Research Initiative.* 1-10.

Fraser, S. W. & Greenhalgh, T. (2001). Coping with complexity: Educating for capability. *British Medical Journal, 323*(7316), 799-803.

Freeman, S., O'Connor, E., Parks, J. W., Cunningham, M., Hurley, D., Haak, D., Dirks, C., & Wenderoth, M. P. (2007). Prescribed active learning increases performance in introductory biology. *CBE – Life Sciences Education, 6,* 132-139.

Freshwater, D. & Rolfe, G. (2001). Critical reflexivity: A politically and ethically engaged research method for nursing. *Journal of Research in Nursing, 6*(1), 526-537.

Friedman, N. D., Temkin, E., & Carmeli, Y. (2016). The negative impact of antibiotic resistance. *Clinical Microbiology and Infections, 22*(5), 416-422.

Friedrichsen, P. J., Sadler, T. D., Graham, K., & Brown, P. (2016). Design of a socio-scientific issue curriculum unit: Antibiotic resistance, natural selection, and modeling. *International Journal of Designs for Learning, 7*(1), 1-18.

Gapinski, A. J. (2010, June 1-4). *Higher education: Europe vs. USA* [Conference presentation]. Latin American and Caribbean Conference for Engineering & Technology, Arequipa, Perú. laccei.org/LACCEI2010-Peru/published/IGE082_Grapinski.pdf.

Gaston, P. L. (2012). *The Challenge of Bologna: What United States higher education has to learn from Europe, and why it matters that we learn it.* Stylus Publishing.

Giddens, J. F. & Brady, D. P. (2007). Rescuing nursing education from content saturation: The case of a concept-based curriculum. *Journal of Nursing Education, 46*(2), 65-69.

Gordillo Altamirano, F. L. & Barr, J. J. (2019). Phage therapy in the postantibiotic era. *Clinical Microbiology Reviews, 32*(2), e00066-18.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2011). Lessons learned about implementing an inquiry-based curriculum in a college biology laboratory classroom. *Journal of College Science Teaching, 40*(3), 45-51.

Gralton, J., Rawlinson, W. D., & McLaws, M. (2013). Health care workers' perceptions predicts uptake of personal protective equipment. *American Journal of Infection Control, 41*(1), 2-7.

Gregory, T. R. (2009). Understanding natural selection: Essential concepts and common misconceptions. *Evolution: Education & Outreach, 2,* 156-175.

Grigoryan, L., Haaijer-Ruskamp, F. M., Burgerhof, J. G. M., Mechtler, R., Deschepper, R., Tambić-Andrasević, A., Andrajati, R., Monnet, D. L., Cunney, R., di Matteo, A., Edelsein, H., Valinteliene, R., Alkerwi, A., Scicluna, E., Grzesiowski, P., Bara, A., Tesar, T., Cizman, M., Campos, J., Stålsby Lundborg, C., & Birkin, J. (2006). Self-medication with antimicrobial drugs in Europe. *Emerging Infectious Diseases, 12*(3), 452-459.

Ha, D., Forte, M. B., Broberg, V., Olans, R., Olans, R., Yong, K. O., Kullar, R., Catipon, N., Ancheta, V., Desai, M., Khattak, Y., Okamoto, D., Lira, D., Chan, S., Mourani, J., Gluckstein, D., & McKinnell, J. (2019). Bedside nurses improve antimicrobial stewardship and infection prevention outcomes: Results of a 3.5-year study in three hospital telemetry units. *Open Forum Infectious Diseases, 6*(S2), S704.

Hagerty, T. A., Samuels, W., Norcini-Pala, A., & Gigliotti, E. (2017). Peplau's theory of interpersonal relations: An alternate factor structure for patient experience data? *Nursing Science Quarterly, 30*(2), 160-167.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66,* 64-74.

Hampton, D., Welsh, D., & Wiggins, A. T. (2020). Learning preferences and engagement level of Generation Z nursing students. *Nurse Educator, 45*(3), 160-164.

Harring, N. & Krockow, E. M. (2021). The social dilemmas of climate change and antibiotic resistance: An analytic comparison and discussion of policy implications. *Humanities & Social Sciences Communications, 8*(125), 1-9.

Hayden, J. K., Smiley, R. A., Alexander, M., Kardong-Edgren, S., & Jeffries, P. R. (2014).

He, Y., Yuan, Q., Mathieu, J., Stadler, L., Senehi, N., Sun, R., & Alvarez, P. J. J. (2020). Antibiotic resistance genes from livestock waste: Occurrence, dissemination, and treatment. *NPJ Clean Water, 3,* 4.

Hendricks, S. M. & Wangerin, V. (2017). Concept-based curriculum: Changing attitudes and overcoming barriers. *Nurse Educator, 42*(3), 138-142.

Höjer, M. & Mattsson, L. (2000). Determinism and backcasting in future studies. *Futures, 32*, 613-634.

Holmes, P., Cockburn-Wootten, C., Motion, J., Zorn, T. E., & Roper, J. (2005). Critical reflexive practice in teaching management communication. *Business Communication Quarterly, 68*(2), 247-256.

Hood, S., Barrickman, N., Djerdjian, N., Farr, M., Magner, S., Roychowdhury, A., Gerrits, R., Lawford, H., Ott, B., Ross, K., Paige, O., Stowe, S., Jensen, M., & Hull, K. (2021). "I like and prefer to work alone": Social anxiety, academic self-efficacy, and students' perception of active learning. *CBE – Life Sciences Education, 20*(1), ar12.

Huang, F., Armando, M., Dufau, S., Florea, O., Brouqui, P., & Boudjema, S. (2021). COVID-19 outbreak and healthcare worker behavioral change toward hand hygiene practices. *Journal of Hospital Infection, 111,* 27-34.

Hulscher, M. E. J. L., van der Meer, J. W. M., & Grol, R. P. T. M. (2010). Antibiotic use: How to improve it? *International Journal of Medical Microbiology, 300*(6), 351-356.

Irvine, S., Williams, B., Smallridge, A., Solomonides, I., Gong, Y. H., & Andrew, S. (2021). The self-regulated learner, entry characteristics and academic performance of undergraduate nursing students transitioning to university. *Nurse Education Today, 105,* 105041.

Jones, A., Buntting, C., Hipkins, R., McKim, A., Conner, L., & Saunders, K. (2012). Developing students' futures thinking in science education. *Research in Science Education, 42*(4), 687-708.

Kalinowski, S. T., Leonard, M. J., Andrews, T. M., & Litt, A. R. (2013). Six classroom exercises to teach natural selection to undergraduate biology students. *CBE – Life Sciences Education, 12*, 483-493.

Kantor, S A. (2010). Pedagogical change in nursing education:One instructor's experience. *Journal of Nursing Education, 49*(7), 414-417.

Kelcíkova, S., Skodova, Z., & Straka, S. (2011). Effectiveness of hand hygiene education in a basic nursing school curricula. *Public Health Nursing, 29*(2), 152-159.

Kim, J. S. & Choi, J. S. (2016). Middle East respiratory syndrome-related knowledge, preventive behaviors and risk perception among nursing students during outbreak. *Journal of Clinical Nursing, 25,* 2542-2549.

Knight, J. K. & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4*(4), 298-310.

Kuiper, R. A. (2002). Enhancing metacognition through the reflective use of self-regulated learning strategies. *Journal of Continuing Education in Nursing, 33*(2), 78-87.

Kuiper, R. A. & Pesut, D. J. (2004). Promoting cognitive and metacognitive reflective reasoning skill in nursing practice: Self-regulated learning theory. *Journal of Advanced Nursing, 45*(4), 381-391.

Lasater, K. (2011). Clinical judgment: The last frontier for evaluation. *Nurse Education in Practice, 11*, 86-92.

Lee, G. M., Friedman, J. F., Ross-Degnan, D., Hibberd ,P. L., & Goldman, D. A. (2003). Misconceptions about colds and predictors of health service utilization. *Pediatrics, 111*(2), 231-236.

Lescure, D., Paget, J., Schellevis, F., & van Dijk, L. (2018), Determinants of self-medication with antibiotics in European and Anglo-Saxon countries: A systematic review of the literature. *Frontiers in Public Health, 6,* 370-381.

Levin, B. R., Baquero, F., & Johnsen, P. J. (2014). A model-guided analysis and perspective on the evolution and epidemiology of antibiotic resistance and its future. *Current Opinion in Microbiology, 19,* 83-89.

Lewis, L. S. (2014). Outcomes of a concept-based curriculum. *Teaching and Learning in Nursing, 9,* 75-79.

Liu, T., Yu, X., Liu, M., Wang, M., Zhu, X., & Yang, X. (2021). A mixed method evaluation of an integrated course in improving critical thinking and creative self-efficacy among nursing students. *Nurse Education Today, 106,* 105067.

Llewelyn, M. J., Fitzpatrick, J. M., Darwin, E., Tonkin-Crine, S., Gorton, C., Paul, J., Peto, T. E. A., Yardley, L., Hopkins, S., & Walker, A. S. (2017). The antibiotic course has had its day. *British Medical Journal, 358,* j3418.

Lopardo, G. (2017, September 25). R*e: The antibiotic course has had its day.* https://www.bmj.com/content/358/bmj.j3418/rr-45.

MacDougall, C. & Polk, R. E. (2005). Antimicrobial stewardship programs in health care systems. *Clinical Microbiology Reviews, 18*(4), 638-656.

Mainous, A. G., Diaz, V. A., & Carnemolla, M. (2008). Factors affecting Latino adults' use of antibiotics for self-medication. *Journal of the American Board of Family Medicine, 21*(2), 128-134.

Mangena, A. & Chabeli, M. M. (2005). Strategies to overcome obstacles in the facilitation of critical thinking in nursing education. *Nurse Education Today, 25*(4), 291-298.

Marasi, S. (2019). Team-building: Developing teamwork skills in college students using experiential activities in a classroom setting. *Organization Management Journal, 16*(4), 324-337.

Martinez, K. A., Rood, M., Jhangiani, N., Boissy, A., & Rothberg, M. B. (2019). Antibiotic prescribing for respiratory tract infections and encounter length: An observational study of telemedicine. *Annals of Internal Medicine, 170*(4), 275-277.

McCoy, C., Stepanian, D., Stack, C. M., Mehrotra, P., & Gold, H. S. (2018, October 6). *Assessing the needs for antimicrobial stewardship education and acceptance across a spectrum of prescribers, nurses and pharmacists at a large academic medical center* [Conference Presentation].

McMahon, M. A. & Christopher, K. A. (2011). Case study method and problem-based learning: Utilizing the pedagogical method of progressive complexity in nursing education. *International Journal of Nursing Education Scholarship, 8*(1), ar22.

McVicar, A., Andrew, S., & Kemble, R. (2014). Biosciences within the pre-registration (pre-requisite) curriculum: An integrative literature review of curriculum interventions 1990-2012. *Nurse Education Today, 34,* 560-568.

Merrill, K., Hanson, S. F., Sumner, S., Vento, T., & Veillette, J. (2019). Antimicrobial stewardship: Staff nurse knowledge and attitudes. *American Journal of Infection Control, 47*(10), 1219-1224.

Michael, C. A., Dominey-Howes, D., & Labbate, M. (2014). The antimicrobial resistance crisis: Causes, consequences, and management. *Frontiers in Public Health, 2,* 1-8.

Middleton, R. (2013). Active learning and leadership in an undergraduate curriculum: How effective is it for student learning and transition to practice? *Nurse Education in Practice, 13,* 83-88.

Miles, M. B. & Huberman, A. M. (1994). *Qualitative Data Analysis: An expanded sourcebook.* SAGE.

Miller, M. A. & Malcolm, N. S. (1990). Critical thinking in the nursing curriculum. *Nursing and Health Care, 11,* 67-73.

Mills, M. D. (2016). Why is health care so expensive in the United States? *Journal of Applied Clinical Medical Physics, 17*(3), 1-4.

Mitchell, G. J., Jonas-Simpson, C. M., & Cross, N. (2013). Innovating nursing education: Interrelating narrative, conceptual learning, reflection, and complexity science. *Journal of Nursing Education and Practice, 3*(4), 30.

Monsees, E., Goldman, J., & Popejoy, L. (2017). Staff nurses as antimicrobial stewards: An integrative literature review. *American Journal of Infection Control, 45*(8), 917-922.

Moore, L. D., Robbins, G., Quinn, J., & Arbogast, J. W. (2021). The impact of COVID-19 pandemic on hand hygiene performance in hospitals. *American Journal of Infection Control, 49*(1), 30-33.

Nehm, R. H. & Schonfeld, I. S. (2010). The future of natural selection knowledge measurement: A reply to Anderson et al. (2010). *Journal of Research in Science Teaching, 47*(3), 358-362.

Nisbet, E. K. L. & Glick, M. L. (2008). Can health psychology help the planet? Applying theory and models of health behaviour to environmental actions. *Canadian Psychology, 49*(4), 296-303.

Norman-McKay, L. (2018). Microbiology in nursing and allied health (MINAH) undergraduate curriculum guidelines: A call to retain microbiology lecture and laboratory courses in nursing and allied health programs. *Journal of Microbiology & Biology Education, 19*(1), n.p.

Novo, A., André, S., Viana, P., Nunes, O. C., & Manaia, C. M. (2013). Antibiotic resistance, antimicrobial residues and bacterial community composition in urban wastewater. *Water Research, 47*, 1875-1887.

Olans, R. N., Olans, R. D., & DeMaria, A. (2016). The critical role of the staff nurse in antimicrobial stewardship—unrecognized, but already there. *Clinical Infectious Diseases, 62*(1), 84-89.

Opal, S. M. (2016). Non-antibiotic treatments for bacterial diseases in an era of progressive antibiotic resistance. *Critical Care, 20,* 397-400.

Osborn, H. K. & Mumford, M. D. (2006). Creativity and planning: Training interventions to develop creative problem-solving skills. *Creativity Research Journal, 18*(2), 173-190.

Owens, R. C. (2008). Antimicrobial stewardship: Concepts and strategies in the 21st century. *Diagnostic Microbiology and Infectious Diseases, 61,* 110-128.

Paige, K. & Lloyd, D. (2016). Use of future scenarios as a pedagogical approach for science teacher education. *Research in Science Education, 46*, 263-285.

Pardue, K. T., Tagliareni, M. E., Valiga, T., Davison-Price, M., & Orehowsky, S. (2005). Substantive innovation in nursing education: Shifting the emphasis from content coverage to student learning. *Nursing Education Perspectives, 26*(1), 55-57.

Patel, A., Pfoh, E. R., Misra Hebert, A. D., Chaitoff, A., Shapiro, A., Gupta, N., & Rothberg, M. B. (2020). Attitudes of high versus low antibiotic prescribers in the management of upper respiratory tract infections: A mixed methods study. *Journal of General Internal Medicine, 35,* 1182-1188.

Paterson, D. L. (2008). Impact of antibiotic resistance in Gram-negative bacilli on empirical and definitive antibiotic therapy. *Clinical Infectious Diseases*, *47*(51), 514-520.

Perkins, C. (2019). Enhanced bioscience content is urgently needed in UK pre-registration nursing curricula. *Nurse Education in Practice, 34,* 7-11.

Petersen, I. & Hayward, A. C. (2007). Antibacterial prescribing in primary care. *Journal of Antimicrobial Chemotherapy, 60*(S1), i42-i47.

Pires, D. P., Costa, A. R., Pinto, G., Meneses, L., & Azeredo, J. (2020). Current challenges and future opportunities of phage therapy. *FEMS Microbiology Reviews, 44*(6), 684-700.

Podolsky, S. H. (2018). The evolving response to antibiotic resistance (1945-2018). *Palgrave Communications, 4*(124).

Pollock, S. J. & Finkelstein, N. D. (2008). Sustaining educational reforms in introductory physics. *Physical Review Physics Education Research, 4,* 010110.

Rábano-Blánco, A., Domínguez-Martís, E. M., Mosteiro-Miguéns, D. G., Friere-Garabal, M., & Novío, S. (2019). Nursing students' knowledge and awareness of antibiotic use, resistance and stewardship: A descriptive cross-sectional study. *Antibiotics, 8,* 203-221.

Rains, J. W. & Barton-Kriese, P. (2001). Developing political competence: A comparative study across disciplines. *Public Health Nursing, 18*(4), 219-224.

Ray, M. J., Tallman, G. B., Bearden, D. T., Elman, M. R., & McGregor, J. C. (2019). Antibiotic prescribing without documented indication in ambulatory care clinics: National cross sectional study. *BMJ, 367,* n.p.

Rees, E. E., Ng, V., Gachon, P., Mawudeku, A., McKenney, D., Pedlar, J., Yemshanov, D., Parmely, J., & Knox, J. (2019). Risk assessment strategies for early detection and prediction of infectious disease outbreaks associated with climate change. *Canada Communicable Disease Report, 45*(5), 199-126.

Reid, J. & Bromiley, M. (2012). Clinical human factors: The need to speak up to improve patient safety. *Nursing Standards, 26*(35), 35-40.

Reis Girondi, J. B., Bolella, V. R., Vieira Tourinho, F. S., Amante, L. N., da Silva Knihs, K. C. N. N., Sebold, F., & Ropelanto Fernandez, D. L. (2017). Team-based learning in the teaching of perioperative care in undergraduate nursing. *International Journal of Nursing Didactics, 7,* 76-80.

Rex, J. H., Fernandez-Lynch, H., Cohen, I. G., Darrow, J. J., & Outterson, K. (2019). Designing development programs for non-traditional antibacterial agents. *Nature Communications, 10,* 3416.

Richard, M., Coley, J. D., & Tanner, K. D. (2017). Investigating undergraduate students' use of intuitive reasoning and evolutionary knowledge in explanations of antibiotic resistance. *CBE – Life Sciences Education, 16*(ar55), 1-16.

Richardson, V. (1994). Conducting research on practice. *Educational Researcher, 23*(5), 5-10.

Rikard, R. V., Thompson, M. S., McKinney, J., & Beauchamp, A. (2016). Examining health literacy disparities in the United States: A third look at the National Assessment of Adult Literacy (NAAL). *BMC Public Health, 16*(975), 1-11.

Robinson, J. (2003). Future subjunctive: Backcasting as social learning. *Futures, 35,* 839-856.

Rodríguez-Verdugo, A., Lozano-Huntelman, N., Cruz-Loya, M., Savage, V., & Yeh, P. (2020). Compounding effects of climate warming and antibiotic resistance. *iScience, 23,* 1-15.

Rose, J., Crosbie, M., & Stewart, A. (2021). A qualitative literature review exploring the drivers influencing antibiotic over-prescribing by GPs in primary care and recommendations to reduce unnecessary prescribing. *Perspectives in Public Health, 141*(1), 19-27.

Saarmann, L., Freitas, L., Rapps, J., & Riegel, B. (1992). The relationship of education to critical thinking ability and values among nurses: Socialization into professional nursing. *Journal of Professional Nursingm, 8*(1), 26-34.

Safazadeh, S., Irajpour, A., Alimohammadi, N., & Haghani, F. (2018). Exploring the reasons for theory-practice gap in emergency nursing education: A qualitative research. *Journal of Education and Health Promotion, 7,* 132.

Sagaldo-Peralvo, A. O., Kewalramani, N., Peña-Cardelles, J. F., Mateos-Moreno, M. V., Monsalve-Guil, L., Jiménez-Guerra, Á., Ortiz-Garcîa, L., & Velasco-Ortega, E. (2021). Preventative antibiotic prescribing habits among professionals dedicated to oral implantology: An observational study. *Antibiotics, 10,* 301-312.

Saldaña, J. (2015). *The coding manual for qualitative researchers.* SAGE.

Schuts, E. C., Hulscher, M. E. J. L., Mouton, J. W., Verduin, C. M., Cohen Stuart, J. W. T., Overdiek, H. W. P. M., van der Linden, P. D., Natsch, S., Hertogh, C. M. P. M., Wolfs, T. F. W., Schouten, J. A., Kullberg, B. J., & Prins, J. M. (2016). Current evidence on hospital antimicrobial stewardship objectives: A systematic review and meta-analysis. *Lancet Infectious Diseases, 16*(7), 847-856.

Smith, L. & Coleman, V. (2008). Student nurse transition from traditional to problem-based learning. *Learning in Health and Social Care, 7*(2), 114-123.

Smith, D. M., Dolk, F. C. K., Pouwels, K. B., Christie, M., Robothan, J. V., & Smieszek, T. (2018). Defining the appropriateness and inappropriateness of antibiotic prescribing in primary care. *Journal of Antimicrobial Chemotherapy, 73*(S2), ii11-ii18.

Sodhi, K., Shrivastava, A., Arya, M., & Kumar, M. (2013). Knowledge of infection control practices among intensive care nurses in a tertiary care hospital. *Journal of Infection and Public Health, 6*(4), 269-275.

Stallins, J. A. & Strosberg, S. (2020). Ontology, difference, and the antimicrobial resistance timeline. *Futures, 115*, e102467.

Stern, J., Ferraro, K., & Mohnkern, J. (2017). *Tools for Teaching Conceptual Understanding: Assessments for Deep Learning.* Corwin Press.

Stevens, A. M., Smith, A. C., Marbach-Ad, G., Balcom, S. A., Buchner, J., Daniel, S. L., DeStefano, J. J., el-Sayed, N. M., Frauwirth, K., Lee, V. T., McIver, K. S., Melville, S. B., Mosser, D. M., Popham, D. L., Scharf, B. E., Schubot, F. D., Seyler, R. W., Shields, P. A., Song, W., Stein, D. C., Stewart, R. C., Thompson, K. V., Yang, Z., & Yarwood, S. A. (2017). Using a concept inventory to reveal student thinking associated with common misconceptions about antibiotic resistance. *Journal of Microbiology & Biology Education, 18*(1), 1-10.

Stivrs, T. & Timmermans, S. (2021). Arriving at no: Patient pressure to prescribe antibiotics and physicians' responses. *Social Science & Medicine*, online preprint.

Sturmberg, J. P. & Martin, C. M. (2009). Complexity and health – yesterday's traditions, tomorrow's future. *Journal of Evaluation in Clinical Practice, 15,* 543-548.

Suda, K. J., Roberts, R. M., Hunkler, R. J., & Taylor, T. H. (2016). Antibiotic prescriptions in the community by type of provider in the United States, 2005-2010. *Journal of the American Pharmacists Association, 34*(5), 422-434.

Svanum, S. & Bigatti, S. M. (2009). Academic course engagement during one semester forecasts college success: Engaged students are more likely to earn a degree, do it faster, and do it better. *Journal of College Student Development, 50*(1), 120-132.

Svensson, E. I. & Berger, D. (2019). The role of mutation bias in adaptive evolution. *Trends in Ecology & Evolution, 34*(5), 422-434.

Taylor, V., Ashelford, S., Fell, P., & Goacher, P. J. (2015). Biosciences in nurse education: Is the curriculum fit for practice? Lecturers' views and recommendations from across the UK. *Journal of Clinical Nursing, 24,* 2797-2806.

Teixeira Rodrigues, A., Roque, F., Piñeiro-Lamas, M., Falcão, A., Figueiras, A., & Herdeiro, M. T. (2019). Effectiveness of an intervention to improve antibiotic-prescribing behavior in primary care: A controlled, interrupted time-series study. *Journal of Antimicrobial Chemotherapy, 74*(9), 2788-2796.

Theobald, R. & Freeman, S. (2014). Is it the intervention or the students? Using linear regression to control for student characteristics in undergraduate STEM education research. *CBE – Life Sciences Education, 13,* 41-48.

Timmins, F. (2006). Critical practice in nursing care: Analysis, action, and reflexivity. *Nursing Standard, 20*(39), 49-54.

Totora, G. J., Funke, B. R., & Case, C. L. (Eds.). (2016). *Microbiology: An Introduction.* Pearson.

Ulenaers, D., Grosemans, J., Schrooten, W., Bergs, J. (2021). Clinical placement experience of nursing students during the COVID-19 pandemic: A cross-sectional study. *Nurse Education Today, 99,* 104746.

van Dyke, G. J. (2014). Educating for EU Citizenship and civic engagement through active learning. In S. Baroncelli, R. Farneti, I. Horga, & S. Vanhoonacker (eds.), *Teaching & learning the European Union: Traditional and innovative methods.* Springer.

van Saene, H. K., Taylor, N., Damjanović, V., & Sarginson, R. E. (2008). Microbial gut overgrowth guarantees increased spontaneous mutation leading to polyclonality and antibiotic resistance in the critically ill. *Current Drug Targets, 9*(5), 419-421.

Ventola, C. L. (2015). The antibiotic resistance crisis. *Pharmacy and Therapeutics, 40*(4), 277-283.

Voros, J. (2003). A generic foresight process framework. *Foresight, 5*(3), 10-21.

Walker, S. B. & Rossi, D. M. (2021). Personal qualities needed by undergraduate nursing students for a successful work integrated learning (WIL) experience. *Nurse Education Today, 102,* 104396.

Wang, Y., Deng, Z., & Shi, D. (2021). How effective is a mask in preventing COVID-19 infection? *Medical Devices & Sensors, 5,* e10163.

Warrens, M. J. (2015). Five ways to look at Cohen's kappa. *Journal of Psychology and Psychotherapy, 5*(4), 197.

Weidman, J. (2006). Socialization of student in higher education: Organizational perspectives. In C. F. Conrad & R. C. Serlin (eds.), *The SAGE Handbook for Research in Education.* SAGE.

Wentzel, J., van Drie-Pierik, R., Nijdam, L., Geesing, J., Sanderman, R., & van Gemert-Pijnen, J. E. W. C. (2016). Antibiotic information application offers nurses quick support. *American Journal of Infection Control, 44*(6), 677-684.

Willman, A., Bjuresäter, K., & Nilsson, J. (2020). Insufficiently supported in handling responsibility and demands: Findings from a qualitative study of newly graduated nurses. *Journal of Clinical Nursing, 30*(1-2), 83-92.

Wilton, M., Gonzalez-Niño, E., McPartlan, P., Terner, Z., Christoffersen, R. E., & Rothman, J. H. (2019). Improving academic performance, belonging, and retention through increasing structure of an introductory biology course. *CBE – Life Sciences Education, 18*(4), ar53.

World Health Organization. (2009). *Glove Use Information Leaflet* [Brochure]. Retrieved from https://www.who.int/gpsc/5may/Glove_Use_Information_Leaflet.pdf.

World Health Organization. (2015). *Antibiotic Resistance: Multi-Country Public Awareness Survey.* Geneva.

Zhang, C., Fang, R., Zhang, R., Hagger, M. S., & Hamilton, K. (2020). Predicting hand washing and sleep hygiene behaviors among college students: Test of an integrated social-cognition model. *International Journal of Environmental Research and Public Health, 17,* 1209-1231.