Summer 2023

Utilizing Case Studies to Increase Critical Thinking in an Undergraduate Anatomy & Physiology Classroom

Sarah E. Lehman

Utilizing Case Studies to Increase Critical Thinking in an Undergraduate Anatomy & Physiology Classroom

By

Sarah E. Lehman

Bachelor of Science
Taylor University, 1999

Master of Arts
University of Findlay, 2001

Master of Science
University of Nebraska at Kearney, 2018

Submitted in Partial Fulfillment of the Requirements

For the Degree of Doctor of Education in

Curriculum & Instruction

College of Education

University of South Carolina

2023

Accepted by:

Christine Lotter, Major Professor

Ashley Gess, Committee Member

Stephen Thompson, Committee Member

Bert Ely, Committee Member

Ann Vail, Dean of the Graduate School

Dedication

***To my husband**: You are the better part of me. I am eternally grateful for the endless loads of laundry completed, dishes washed, and moments of frustration that you have endured during the completion of this tome. I still choose you. Always.*

***To my boys**: You are the pride and joy of my life. Watching you grow up and become delightful young men has been a privilege. Never forget that grit and determination can take you places you never dreamed of going. I love you both.*

Abstract

The purpose of this study was to determine the effectiveness of the implementation of case-based learning compared to traditional lecture in increasing critical thinking skills in an undergraduate Anatomy & Physiology I classroom. Throughout the course of one semester, five units were taught with the addition of a case study as an instructional tool while the other four units were taught utilizing only didactic (lecture) methods and did not teach content utilizing case study methodology. Two types of content-specific critical thinking data were analyzed: selected multiple-choice exam questions and End of Chapter (EOC) assignments. The Cornell Critical Thinking Test (CCTT) was administered at the beginning and end of the semester to measure general critical thinking skill progress throughout the course. In addition, the Student Assessment of Learning Gains (SALG) survey was administered at the end of the semester to measure student perception of learning via different teaching methodologies. Exam data indicated a growth in content-specific critical thinking throughout the semester while EOC data were inconclusive. The CCTT data showed an overall lack of change in critical thinking skills. Students perceive case studies as generally helpful for learning, but rate lecture and laboratories as providing more assistance in learning course material.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

As I walked off the stage, having just graduated from my undergraduate institution with a degree in Biology Education, I felt equipped to implement high-quality science instruction in my first teaching job at a high school in northwest Ohio. In those first few years of teaching, I had students performing active learning in many forms: problem-based instruction, inquiry laboratory investigations, and group work galore. I differentiated instruction and attempted to have students experience science and not just memorize a catalog of facts. When I made the transition to teaching at the undergraduate level, I immediately felt helpless. I asked myself, “How can I incorporate best practices, including active learning strategies, and still get through the amount of material required in my undergraduate courses?” I understood that involving students in the active construction of knowledge was important to develop critical thinking skills, but there was just too much information to cover in such a short amount of time. At the high school level, I worked with students for at least 40 minutes every day of the week for a total of almost 7,200 minutes per year. In the undergraduate environment, I was able to meet with students for 50 minutes, three times a week, for 15 weeks. The approximately 2,250 minutes that I was able to connect with students seemed to pale in comparison to my experience at the high school level, but I felt obligated to cover the same amount of material, if not more.

Over the last seven years of full-time collegiate teaching, I have attempted to solve this problem in different ways, but often I have fallen back into the routine of lecturing for a large portion of my class time with students. This methodology has seemed to be the only way to cover the amount of material expected in the allotted time. In some courses, the content load is a bit lower, and I have the ability to add in more of the active learning strategies which I utilized at the high school level. In other courses, such as my Anatomy & Physiology course, I feel very constrained by the breadth of content. A large percentage of my students are planning to pursue additional studies in professional schools in the areas of physical therapy, medicine, dentistry, optometry, nursing, and veterinary medicine and will be expected to have knowledge of and be able to apply information from each of the human body systems. As such, the concept of reducing the amount of material and not being able to cover all systems does not adequately serve my students as exposure to this material is crucial to their future success. While active learning strategies, in my experience, have been effective in positively impacting higher-order learning, I find they often require more time in class and reduce the overall coverage of material throughout the course.

In addition to content, I see the deep need for students to be able to think critically and be able to apply the knowledge they have gained. Since many of my students hope to attend professional school, they need to be able to perform well on tests that require critical thinking in the form of application of anatomy & physiology concepts such as the NCLEX (National Council Licensure Examination), DAT (Dental Admission Test), OAT (Optometry Admission Test), MCAT (Medical College Admission

Test) and the GRE (Graduate Record Examination). Because I perceive it is my responsibility to help prepare them for such exams, I desire to help students develop their critical thinking skills throughout my course.

At the end of the day, I continue to try to answer the question: "How can I effectively increase content mastery and critical thinking skills by incorporating active learning activities into the collegiate Anatomy and Physiology classroom without sacrificing content?" My goal is for students to actively wrestle with and increase their ability to think critically about the content, thus allowing them to become more successful in their chosen career. Knowing that increasing active learning is a means to this end, I want to incorporate active learning strategies more effectively into my classroom.

Problem Statement

The term 'critical thinking' is used widely in education but is often difficult to explain discretely and different definitions are common in the literature. A common definition of critical thinking and the one utilized throughout this study is one developed by The Delphi Report (Facione, 1990). According to this group of critical thinking scholars, critical thinking is defined as "…purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based" (as cited in Dwyer et al., 2014, p. 47).

The ability to think critically is considered an essential component of competent citizenship as participation in a democracy requires the ability to make informed decisions based on this skill (Abrami et al., 2015; Mason et al., 2018; McMurray et al., 1989). Often, the ability to think critically is thought to be one of the main objectives in an undergraduate education and is the skill most sought after by employers when hiring recent undergraduates (Davies, 2013; Rayner & Papakonstantinou, 2018). Critical thinking is not only a skill that is looked upon highly by employers; it is necessary for those students wishing to continue their education in the medical profession. Critical thinking skills have a high correlation with success in post-graduate schools of nursing, medicine, dentistry, physical and occupational therapy, chiropractic, veterinary, and dietetics (Romeo, 2013; Ross et al., 2013; Siebert, 2021).

Unfortunately, while critical thinking appears to be an essential skill for undergraduate to master, colleges and universities seem to be lacking when it comes to achieving this learning objective. The Collegiate Learning Assessment, an instrument utilized in higher education to measure an institution's contribution to student learning, has shown that undergraduates do not significantly improve in critical thinking over the course of a four-year degree (Grant & Smith, 2018). This poor performance is not surprising given that while a vast majority (89%) of surveyed undergraduate instructors agreed that teaching critical thinking is essential, only 9% felt that they were teaching these skills (Abrami et al., 2015). Davies (2013) states that without dedicated, purposeful instruction, there will be minimal improvement in critical thinking skills over the course of an undergraduate career.

Lecturing as a means to distribute large volumes of information has been the most common form of learning in undergraduate institutions since the advent of universities in Western Europe over 900 years ago (Freeman et al., 2014). In recent years, however, studies have shown that lecturing is not the most effective technique to promote the retention of challenging information (Lax, Morris, & Kolber, 2017). More specifically, this content-based delivery of information largely disregards critical thinking (Santos, 2017). Active learning, in contrast, “engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work” (Freeman et al., 2014, p. 4-5). When utilized in a classroom setting, active learning has been shown to improve exam scores by a significant margin (Jensen, Kummer, & Godoy, 2014; Theobald et al., 2020) and increase critical thinking (Amin et al., 2019; Rosenberg & Dibner, 2018) in Science, Technology, Engineering, and Mathematics (STEM) disciplines.

This approach is much different than the lecture approach because of the passive role that students play in most lecture-based courses. While active learning has been at the forefront of educational research for some time, many professors feel that they do not have time to implement active learning in their classrooms (Styers, VanZandt, & Hayden, 2018). In addition, professors experience difficulty designing courses that incorporate active learning and thus increasing critical thinking in the classroom (McLean et al., 2015; Tharayil et al., 2018).

Since I find myself struggling with these same issues, the problem of practice I have identified is the lack of critical thinking skills gained in my collegiate level Anatomy & Physiology course and the inability to incorporate meaningful active learning without sacrificing the amount of content covered in the course. Lecturing is the most efficient way to distribute large amounts of information (Poirier, 2017) and my introductory Anatomy & Physiology course is expected to cover a wide range of information including all body systems since it is a prerequisite for other courses in multiple fields. While I understand that the incorporation of active learning in my classroom helps to foster critical thinking skills, it is difficult to find large spans of time to devote to active learning as this often reduces the amount of material that I can cover in the class. Throughout this study, I implemented case-based learning as a method of incorporating high-impact active learning activities that are short in duration to foster critical thinking in my students.

Case-based learning (CBL) is also known as case study teaching or case method learning and is an active learning instructional strategy that has been implemented in various educational settings. At its core, CBL is a teaching methodology utilizing stories that carry an educational message (Harman et al., 2015). While the format of CBL varies, it is often described as an instructional strategy under the umbrella of problem-based learning (Abercrombie et al., 2019; Kulak & Newton, 2014). Problem-based learning (PBL) is an instructional approach characterized by very open-ended, student-directed, and interdisciplinary instruction with minimal lecturing (Hopper, 2018; Savery, 2006). In PBL, the problem forms the base of the entire curriculum. As a methodology related to PBL, case-based learning is typically more structured, less complex, and addresses pre-determined learning outcomes (Kulak & Newton, 2014). Cases can be used for multiple purposes such as teaching content, analyzing real-life data, and practicing decision-making (Hartfield, 2010) and is based on the premise that the context of the learning is just as important as the material itself (Lave & Wenger, 1991; Thistlethwaite et al., 2012).

Theoretical Framework

The theoretical framework for this study is informed by both Constructivism and Situated Cognition Theory. Case-based learning provides opportunities for students to systematically construct knowledge in a step-by-step fashion that efficiently scaffolds information (Burgess et al., 2021). In my classroom, cases were utilized in a group setting which further amplifies their effectiveness as learning is occurring with peers.

Constructivism is more of a psychological and philosophical perspective than a theory but has been informed by theories developed by both Piaget and Vygotsky (Schunk, 2020). The constructivist paradigm posits that learning is “an active process in which learners are active sense-makers who seek to build coherent and organized knowledge (Baeten et al., 2013, p. 486). More specifically, learning and meaning, as seen through the constructivist lens, is facilitated when learners link existing information with new information that is presented (Michael, 2006; Voon et al., 2020). In this way, learning is seen as a step-by-step process with each subsequent step building on the last. Social constructivism, initially advanced by Vygotsky, is seen as a subset of constructivism and posits that the construction of learning happens more effectively when individuals work in groups (Shepardson & Britsch, 2015).

Situated cognition theory proposes that the construction of knowledge is best practiced within a real-world learning context (Donaldson et al., 2020). This theory, first formally identified by Lave and Wenger (1991), provides a way to look at understanding learning by focusing on the following themes: community of practice, authentic context, and embodiment (Donaldson et al., 2020). Instruction that allows students to solve real-world problems can be beneficial to students as they are more likely to be able to transfer their knowledge from the classroom to different environmental contexts when those concepts are initially studied in a realistic context (Prince & Felder, 2006).

Case-based learning seeks to incorporate both theories into an effective package for student learning. The use of cases in instruction is based in a specific subset of constructivism known as discovery learning which was developed by Jerome Bruner in the 1960s (Hartfield, 2010). In discovery learning, students learn by doing as opposed to learning by listening. Case-based learning, compared to other active learning strategies, is often completed in groups rather than individually and uses context to strengthen connections between concepts. In this way, cases blend active and interactive components and thus integrate cognitive and social models of learning (Thistlethwaite et al., 2012).

Purpose Statement

The purpose of this study was to discover how the addition of active learning strategies impacts critical thinking and perceptions of learning in my current context of undergraduate Anatomy & Physiology instruction. All classrooms have different expectations and outcomes and I want to identify how to best incorporate active learning in this unique environment and thus foster critical thinking in my students. Is the case study method of teaching a viable technique?

Research Questions & Hypotheses

For this study, two research questions with their corresponding null and alternative hypotheses were brought forth.

1. How does the implementation of active learning in the form of case studies impact critical thinking in my Anatomy & Physiology classroom?

   Null hypothesis (H_0): There will be no significant difference in the critical thinking scores of students taught by both the experimental method (case studies) and the comparison method (lectures).

   Alternative hypothesis (H_a): There will be a significant positive difference in critical thinking achievement between the two groups with the experimental method showing more growth in critical thinking.

2. How do students perceive case studies to influence learning in my Anatomy & Physiology classroom?

   Null hypothesis (H_0): There will be no significant difference in perception of learning by students when comparing case study instruction and didactic instruction.

   Alternative hypothesis (H_a): There will be a significant positive difference in student perception of learning between the experimental methodology and the comparison approach.

Positionality Statement

When completing a research project involving human subjects, it is important for the researcher to identify their positionality in reference to the study participants.

Positionality “both describes an individual’s world view and position they adopt about a research task and its social and political context” (Holmes, 2020, p. 1). Knowing that both researcher and participants impact the research process, it is important that the researcher identify ways in which their position may impact the outcome and process of a study.

I am currently an assistant professor of biology at a very small, private, liberal arts university in the Midwest United States with an undergraduate enrollment of about 750 students. The outlined research took place within the course BIO 230, Anatomy & Physiology I, which is a 4-hour semester-long course and is offered one time each year. This course typically enrolls around 50 students which are a mixture of primarily freshman and sophomores with limited exposure to college science courses. Each year, most students that are in my course share a similar background to myself including being white and from small communities in the surrounding area. As I am both the instructor of record of this course and the experimenter, I am considered an insider in relationship to this study on case study implementation. All students enrolled in this course are also insiders as they are on the receiving end of the case study model.

This positionality confers some benefits, most notably that the students and I are in a consistent relationship with each other, and I know them well. I can understand their needs and where they have come from academically. Additionally, I share a similar race and cultural background with many of the students. Throughout this course, I see each student four times a week, and one of these times is in a smaller, focused setting in the laboratory. In these smaller settings, students often are vulnerable about their current and past life experiences which can give me insight into their needs in the classroom. I often ask them questions about their experience in the course and identify areas in which they struggle. While this can be seen as a benefit, this close relationship can also be a detriment. If I am soliciting feedback about a particular strategy utilized in the classroom, students can be hesitant to share honest opinions as they do not want to hurt my feelings. In addition, because I am the instructor of record and determine their final grade for the course, this can place me in a position of power over students and could potentially introduce bias into the study design. This power dynamic is most evident in the portion of the study where students' opinions about the instructional methodology are gathered.

Bias can also be introduced into the study by the researchers having preconceived notions of how the study will proceed. While it is my belief that students will have greater success when exposed to a case study model of instruction, it is imperative that my own thoughts about appropriate learning techniques did not influence the results. While the quantitative nature of the study should help control for these biases, great care was taken to measure learning and perceptions of learning appropriately and without bias. Personal student opinions about teaching methodology will be communicated anonymously and students will be assured that no response or opinion will in any way affect their grade in the course.

Research Design

I functioned as researcher and instructor in this quasi-experimental participatory action research study. Participatory action research seeks to address problems within the context of an individual’s specific environment (Efron & Ravid, 2020), and since the data were collected in my local 4-year, private university environment, this type of study was appropriate. Within this setting, I investigated how active learning, in the form of case studies, effects critical thinking skills in an Anatomy & Physiology classroom. This study was “designed to gather numerical data from individuals…using statistical tests to analyze the data collected” (Effron & Ravid, 2020, p. 48) and it hence was quantitative in nature. Various data in the form of test & homework scores were collected to determine change in critical thinking over the course of the semester and in response to two different teaching methodologies: lecture and case-based learning. Additionally, students completed a Likert scale survey about how they perceived the cases to assist in their learning of the course material, and these data were assessed quantitatively. This methodology was chosen for the study because I was attempting to identify a cause-and-effect relationship, and quantitative data is more appropriate to identify this correlation (Effron & Ravid, 2020).

The study took place in the fall of 2022 in my Anatomy & Physiology I class (BIO 230) with all enrolled students (n=50) participating in the study. Content in the course is broken down into nine units/chapters including: Introduction to Anatomy & Physiology (A&P), Chemical Basis of Life, Cell Biology, Tissues, Integumentary System, Skeletal System, Muscular System, Nervous Tissue, and Special Senses. Four of the units were taught in the traditional format, consisting largely of whole-group lecture, while the other five units consisted of lecture plus the addition of a case study that is responsible for covering some of the course content. The cases were completed in groups of 3-4 students during one day in class and were obtained from the National Center for Case Study Teaching in Science's web repository of cases (University at Buffalo Libraries, n.d.). The units taught in a traditional format received an equal amount of teaching time in the classroom and resulting data were compared. The total time spent on each unit was comparable to the amount of material covered in the unit with no significant difference in teaching time devoted to a particular topic.

Critical thinking skills of the students were evaluated in three different ways. First, critical thinking skills were measured both at the beginning and end of the semester utilizing the Cornell Critical Thinking Test – Level Z (CCTT – Z), a validated instrument to measure critical thinking. Second, critical thinking connected with specific content was measured on each of the exams during the Anatomy & Physiology course. Three exams were given over the duration of the semester with each exam covering two to four of the units in the course. Exams consisted of 50 multiple-choice questions as well as three to four short answer responses, but only eight of the multiple-choice questions were evaluated for critical thinking skills. No data were collected on the short answer questions. On each exam, four multiple-choice questions were selected that assessed critical thinking utilizing content that was taught in a traditional (lecture) method and four additional questions utilized content taught via case study instruction. Questions were obtained from the test bank that accompanies the textbook selected for the course (Vanputte & Seely, 2022) and were evaluated for Bloom's Taxonomy level by using the Blooming Anatomy Tool (Thomson & O'Loughlin, 2014). Multiple-choice questions were utilized for this study since many of the standardized tests that students will need to take for entrance into professional school (MCAT, DAT, etc.) follow this format.

Figure 1.1 details the levels of questioning in Bloom's Taxonomy and the top four tiers are often linked to a student's ability to think critically as they require a student to make connections between independent pieces of information or apply the information to a new setting (Bibler-Zaidi, 2018; Bissell & Lemons, 2006). For each of the exam given throughout the semester, there were a total of four questions that assessed the "Apply" level and four questions that assessed "Analyze", two from each teaching methodology. The overall scores for the eight selected questions were recorded in a spreadsheet, and the average score in each category was calculated and statistically analyzed. The average score on units that were taught in a traditional manner were compared with those units including a case study to determine the impact on critical thinking ability.

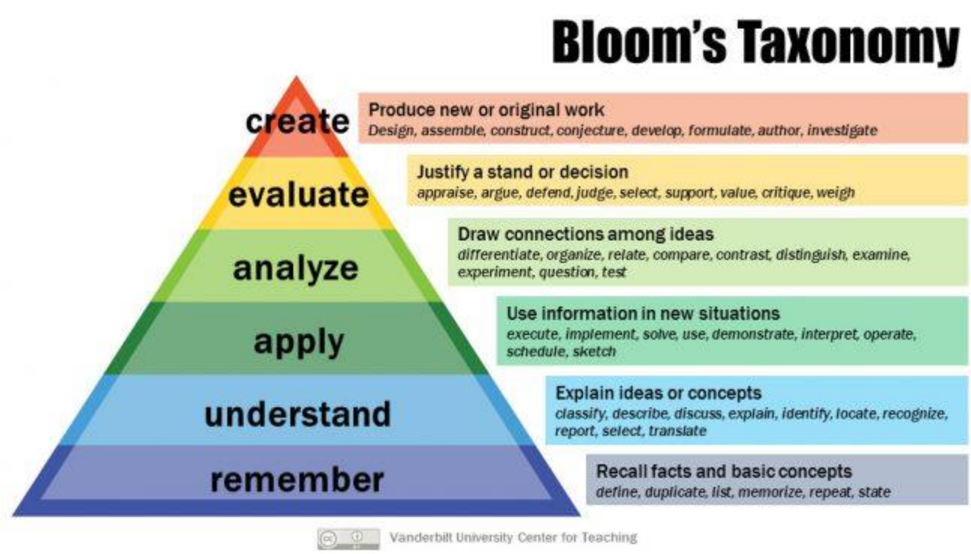

Figure 1.1 *Bloom's Taxonomy*

Note: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

A third source of critical thinking data involved assessing students at the end of each chapter. For the chapters containing a case study, students were asked to answer critical thinking questions concerning the case study completed in class, and the responses were evaluated by a rubric (see Appendix D). At the conclusion of units taught in a traditional manner, students were assigned a short answer homework assignment that required students to utilize critical thinking skills to apply content learned in class. Both types of homework assignment were assessed via a rubric (see Appendix D) and the scores were compared.

At the conclusion of the semester, students were given the opportunity to reflect on the cases through the completion of the Student Assessment of Learning Gains (SALG) survey. The survey asked students questions about their perception of the cases including the helpfulness in learning content compared to learning with didactic instruction. This survey, conducted anonymously during class time with the instructor absent, was composed of questions in a Likert format, and was assessed quantitatively.

Significance and Limitations

Action research is different from traditional research in that action research shifts the control away from academic researchers to local participants and the subject of the research itself (Herr & Anderson, 2015). While a significant amount of research has been done in the areas of active learning and case-based learning, the needs of each classroom differ and the implementation of these techniques will vary. The strategies that are seemingly effective for some may not work in my specific context. Because I sought to solve a problem specific for my context, action research was a more appropriate strategy than traditional research to answer the questions that I was posing.

While the results may be more appropriate for my specific context, they are also potentially transferable to larger communities. Some of the questions that my study sought to answer will be similar across contexts. Most undergraduate Anatomy & Physiology classrooms around the country recognize the need for increased critical thinking (Human Anatomy & Physiology Society [HAPS], 2019) and face similar time constraints thus could gain important insights from this study highlighting ways that active learning can be effectively incorporated. The researcher, through this study, attempted to combine aspects of a more traditional undergraduate classroom while increasing the time spent utilizing active learning in the form of case studies. This combination of traditional instruction with added cases could be utilized across many different disciplines and contexts. This research study also fills a gap in the literature as most studies involving case study implementation in Anatomy & Physiology do not specifically assess critical thinking skills.

While information gathered via this study is helpful for informing further instruction in my context, it does have several limitations. First, because of the time constraints and set-up of my teaching load, there was no control group and no randomization. Ideally, one section of the course taught in a traditional manner would be compared with a different section taught utilizing the addition of case studies. Because I only teach one section of Anatomy & Physiology each fall, this is not possible, hence, the reason that units taught in a different manner were compared for critical thinking outcomes. Second, while exam questions and homework assignments will be similar in difficulty, there is no way to ensure that all assignments are exactly similar in difficulty. Each assignment will contain similar levels of questioning via Bloom's Taxonomy, but there is no way to completely standardize this methodology.

Definition of Terms

Active learning: "Engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (Freeman et al., 2014, p. 4-5).

Bloom's Taxonomy: A framework for categorizing educational goals and questions utilized in the classroom. It was first developed by Benjamin Bloom in 1956 (Adams, 2015; Armstrong, 2010; Thompson & O'Loughlin, 2015).

Case-based learning (CBL): An active learning instructional strategy wherein a story is utilized to show the application of a theory or concept to real-life situations. CBL lessons often have a defined set of objectives, unlike other forms of active learning that are more open-ended (Allchin, 2013; Bansal & Goyal, 2017; Birk et al., 2019; Boston University, n.d.).

Critical thinking (CT): "Purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based" (Facione, 1990, p. 2).

Problem-based learning (PBL): An active learning, student-centered instructional strategy where a problem forms the base of the curriculum. PBL is often very open-ended, interdisciplinary, and contains little to no direct instruction. (Allchin, 2013; Hays, 2008; Hopper, 2018

S.T.E.M.: In the context of this research, STEM refers to any course, field of study, or career that is related to any of the four disciplines of science, technology, engineering or mathematics.

Chapter 2: Literature Review

The primary researcher of this study investigated the effect of active learning in the form of case study implementation on critical thinking and student perception of learning in an undergraduate anatomy and physiology classroom. Students' ability to think critically were measured after completion of lecture-only instruction and after lecture supplemented with case studies.

Need for High-Quality Science Instruction

The need for high-quality science instruction at the undergraduate level has never been more important. Science, as a discipline, is uniquely positioned to help students solve problems methodically and objectively (Kruckeberg, 2006; Santos, 2017) which can impact individual students as well as the society at large. The problem-solving ability developed in science courses is desperately needed by a society facing global issues such as food scarcity, climate change, and novel pandemics (Akiha et al., 2018). Unfortunately, the United States has fallen short in our contributions to some of these global challenges as we have one of the lowest rates of undergraduates entering the STEM fields when compared to 50 other countries (National Science Board, 2020). The low number of STEM graduates not only affects global progress in these efforts but nationally as well, noting that the U.S. does not produce enough STEM graduates to meet economic demands (Akiha et al., 2018). Making progress will require both scientists and non-scientists to accurately evaluate evidence as well as connect information from a variety of sources and disciplines (AAAS, 2011; Lent et al., 2021). High quality science instruction helps to foster the development of these skills in its students.

Instruction in the sciences is also personally helpful in the ways it helps students to become more rational, systems thinkers that helps them make meaningful connections in their experiences (Kruckeberg, 2006). These connections can assist students as they make personal decisions related to human health and environmental stewardship (Labov et al., 2010) and can be of great benefit professionally as well. The modern economy requires employees to synthesize and analyze information (Akiha et al., 2018) and demands complex problem solving over simple information (Wieman, 2017). The skills developed in science courses can help students be better positioned to enter the workforce upon graduation, regardless of discipline. For some students, the skills learned in science courses become a critical step in changing one's life trajectory. Many careers, including those in nursing and allied health, provide a way for students to rise from lower to middle socioeconomic status (Birk et al., 2019) and a science course often is the gateway to these career paths. In these ways, high-quality science instruction can individually impact the lives of the students that take these courses and, at the same time, affect global change.

Current State of Undergraduate Science Education

Before the invention of the printing press, educational institutions relied on oral transmission of information from instructor to pupil as this was the only efficient mechanism to pass along content (Wieman, 2017). This tradition of lecturing has continued to predominate in most undergraduate lecture halls across the country. While lecture may be an efficient mechanism of information transfer, it tends to promote shallow, surface learning (Hobbins et al., 2020; Kaddoura, 2011), provides little feedback to students (Wieman, 2017), and does little to encourage students to identify their misconceptions about the topic and challenge them (Prince & Felder, 2006; Verkade et al., 2017). This type of learning may promote memorization which meets the short-term goal of course completion but does little for long-term knowledge construction (Anthony, 2017).

The exclusive use of lecture instruction seems to have far-reaching impacts. Many developed countries graduate a higher percentage of youth compared with the United States (Arum & Roksa, 2011; National Science Board, 2020) and those that do graduate with a bachelor's degree are unable to understand or evaluate arguments (Davies, 2013), which impacts their ability to think critically about topics. In a large study by Arum and Roksa (2011), critical thinking skills only improved by 0.18 standard deviations after two years of college work, and 45% of students had no significant improvement at all. Comparatively, students of color gained less than their white peers (Arum & Roksa, 2011). These statistics do not bode well for the state of current undergraduate education as our lower number of graduates are less prepared than those from other countries.

While students in the STEM disciplines seem to fare a slight bit better in critical thinking gains than their non-STEM peers (Arum & Roksa, 2011), the overall picture is not terribly positive. After entering college in a STEM field, between 25%-50% of those students will leave the field before completing their degree (Chen, 2013; National Science Board, 2020) and students from low socioeconomic backgrounds are more likely to give up and change their major (Birk et al., 2019). Additionally, students from underrepresented groups start their undergraduate careers with a similar interest in STEM fields compared to other students but have a lower success rate than their peers (Theobald et al., 2020). Students from all backgrounds cite irrelevant (Wieman, 2017) and uninspiring (Akiha et al., 2018) science courses as reasons to leave the STEM disciplines. Since it has been shown that students who are successful in learning disciplinary content are more likely to stay in the STEM fields (Birk et al., 2019), some of this attrition may be due to teaching method in the classroom.

Teaching techniques in science classrooms seem to vary little from undergraduate courses in general. Most science courses at the undergraduate level contain three, 50-minute lectures per week in addition to one 2–3-hour lab (AAAS, 2011; HAPS, 2019). Akiha et al. (2018) measured instructional practices in middle school, high school and undergraduate STEM courses by utilizing a tool called the Reformed Teaching Observation Protocol (RTOP). The RTOP measures the level of student-centered vs. instructor-centered activities utilized in a course with a score of 0 equaling completely instructor-centered (lecturing) and a score of 100 equaling completely student-centered (active learning) instruction. Evaluation of undergraduate STEM courses showed that the average score was a 35.9 with some courses devoting as little as 2% of the time to student-centered instruction (Akhia et al., 2018). Even when instructors have the infrastructure to incorporate more student-centered, active learning environments, lecture still predominates (Stains et al., 2018). Additionally, these courses are often instructor-centered regardless of number of students in the course, the class length, or the presence of a laboratory (Akiha et al., 2018).

These instructor-centered courses based on lecture instruction promote low-level learning and assume that "every student needs the same information presented orally at the same pace" (AAAS, 2011, pgs. 25-26). It is no wonder that students have low levels of learning and thus leave STEM fields. It is with this in mind that many individuals and agencies including the National Research Council, the President's Council of Advisors on Science and Technology, and the American Association for the Advancement of Science call for a radical change in the way that science education is administered at the undergraduate level (AAAS, 2011; Labov, et al., 2010; Stains et al., 2018).

Critical Thinking

The ability to think critically is the skill that citizens need to develop to contribute to society in a positive manner and undergraduate faculty agree, almost unanimously, that teaching students to think critically is the principal aim of a college education (Arum & Roksa, 2011; Grant & Smith, 2018). The American Association of University Professors posits that "critical thinking… is the hallmark of American education – an education designed to create thinking citizens for a free society" (as cited in Arum & Roksa, 2011, pg. 35). The ability to think deeply and critically about different topics in a complex society requires more than the basic ability to read and write (Abrami et al., 2015; McMurray et al., 1989), hence why it is valued by educators, parents, employers, and policymakers alike. When asked, employers rate critical thinking as very important (Arum & Roksa, 2011), and this skill is typically rated as more important than academic qualifications (Davies, 2013; Rayner & Papakonstantinou, 2018).

Development of critical thinking in the context of a science course is integral to the discipline in the Information Age in which we live. By the time students leave the classroom, much of what has been taught during a life science course will have changed (AAAS, 2011) so the ability to think critically will help students entering their respective fields more so than the information itself. Students able to utilize this skill engage in less cognitive bias and make better decisions and judgments (Dwyer et al., 2014), and the American Association of Colleges of Nursing (AACN) has identified critical thinking as one of the major curricular goals in nursing education (AACN, 2022). Science courses seem an ideal place to foster this development as students in these fields see modest growth in critical thinking throughout their undergraduate experience (Arum & Roksa, 2011; Loyalka et al., 2021).

But what is critical thinking? Throughout the literature, critical thinking has been defined in a myriad of ways but at its core, it refers to the quality of thinking being done (Bailin, 2002; Santos, 2017). It is distinguished from lower levels of thinking such as recall and application (Santos, 2017) and is more frequently thought of in terms of processes and skills (Bailin, 2002; Davies, 2013). Many authors have tied the concept of critical thinking to Bloom's Taxonomy, first created by Benjamin Bloom and colleagues in 1956 (Armstrong, 2010), and this tool can be utilized to classify levels of cognitive difficulty. Different cognitive tasks inherently have different levels of difficulty and

Bloom's Taxonomy attempts to organize these tasks in a hierarchy from lower-order skills, requiring less processing to higher-order skills (Adams, 2015). The original taxonomy included six learning objectives: knowledge, comprehension, application, analysis, synthesis and evaluation. Early in the 21st century, a revision to Bloom's was made by cognitive psychologists Lorin Anderson & David Krathwohl (2001) and the revised taxonomy includes the following levels of learning: remember, understand, apply, analyze, evaluate, create (see Figure 1.1). When critical thinking is tied to Bloom's taxonomy, it is connected to the top three levels (Harman et al., 2014), the top four levels (Abrami et al., 2015; Bissell & Lemons, 2006; Kaddoura, 2011; Kulak & Newton, 2015; Ross et al., 2013; Santos, 2017) or the top five levels (Rayner & Papakonstantinou, 2018). As students learn material, they can be guided to progress hierarchically through different learning experiences (Harman et al., 2015).

Researchers have determined that the level and type of critical thinking can be assessed in multiple ways, including multiple-choice questions. Specifically in medical education, Bibler-Zaidi et al. (2018) attests that higher-order multiple-choice questions "are important for stimulating the critical thinking skills that support clinical reasoning" (p. 858). The idea that multiple-choice questions can be utilized to assess critical thinking is affirmed by other authors as well (Ali & Ruit, 2015, Choudhury & Freemont, 2017, Kim et al., 2012, Palmer & Devitt, 2007).

Beyond the definition of critical thinking lies two main questions about critical thinking skills. First, is critical thinking a general skill or is it tied to a specific context? There is a wide range of research in this area and many thoughts as to the appropriate way to answer this question, the conclusions of which are used to determine how critical thinking should be taught. While some researchers conclude that critical thinking is a general skill (Abrami et al., 2015; Davies, 2013) others have found that critical thinking ability varies with content and transferability of critical thinking between disciplines seems to be somewhat limited (Bailin, 2002; Monteiro et al., 2020). Proponents of the discipline-specific nature of critical thinking claim that errors in decision making "derive not from inadequate thinking skills but from inadequate knowledge" (Monteiro et al., 2020, p. 70). These individuals theorize that specific content must first be learned in order to think critically about that discipline and critical judgments cannot be accurately made without a baseline knowledge of content in a specific area.

The second major question posed in the research is, can critical thinking be taught? The answer to this question appears to have a more definitive answer as research has shown that critical thinking can be developed via instruction at all educational levels even though the strategies are varied (Abrami et al., 2015). While many interventions may be useful in developing critical thinking skills, it has been shown that active participation is required (Abrami et al., 2015; Kaddoura, 2011) and two strategies of active learning are especially helpful in this development: discussion amongst peers and exposure to authentic problems (Abrami et al., 2015).

In medical and allied health education, critical thinking has been shown to be especially important. In a meta-analysis of the literature, Ross et al. (2013) found that two different tests of critical thinking positively correlated with success in the careers of medical professionals. Additionally, critical thinking skills are the most accurate predictor of student success on the NCLEX exam which is the certification exam for nursing professionals (Romeo, 2013). Unfortunately, when analyzing most college classrooms in terms of critical thinking, "average professors don't appear to give a hoot about the term" (Herreid, 2004, pg. 12), citing a lack of time to teach critical thinking skills since adequate content coverage is time-consuming (Heath & Weege, 2017). One way that instructors can increase critical thinking skills is looking at learning through the lens of constructivism.

Constructivism

Constructivism is a multifaceted epistemology about the nature of learning which has deep roots all the way back to 6^{th} century B.C. philosophers such as Tzu, Budda, and Heraclitus in addition to the more recent work of Kant and Vico in the 18^{th} century (Prince & Felder, 2006). Modern constructivist thinking is most often attributed to Piaget and Vygotsky and posits that learners construct their own learning (Schunk, 2020). Wieman (2017) accurately describes this type of thinking when he states, "true understanding comes only when students actively construct their own understanding via a process of mentally building on prior thinking and knowledge through 'effortful study'" (p. 9). This type of learning requires a student-centered environment (AAAS, 2011) where active subjects are acquiring knowledge through formation of mental constructs (Krukeberg, 2006).

An important distinction needs to be made between activity of the body and activity of the mind. Just because a student is physically involved in a lesson does not mean that their mind is actively engaged (Bächtold, 2013). Students need to be actively engaged with their mind for authentic learning to take place. Engagement of the mind requires students to use their previous knowledge to answer questions (Colburn, 2000) and build links between that previous knowledge and new concepts (Bächtold, 2013). The student then needs to apply that newly constructed framework in various contexts over a long period of time for learning to occur (Shepardson & Britsch, 2015). In the places where a student's previous knowledge is incorrect, space needs to be made for the student to identify the flaws in their understanding and challenge those ideas. While lecture is not considered an active process, it can be utilized appropriately after students have identified their misconceptions about a topic and are ready to assimilate new information (Colburn, 2000).

There are two main types of constructivism: personal and social. Personal constructivism or cognition is most often connected with the work of Piaget and focuses on the learner's interaction with the material or the personal environment while social constructivism presupposes that the interaction with the social environment is key in the initiation of learning (Bächtold, 2013). Vygotsky is the main individual that is connected with social constructivist theory and he posited that meaning-making occurred best in a social environment where students coordinated their ideas with the ideas of others (Shepardson & Britsch, 2015). In this way students experience a positive interdependence with each other's where each can scaffold the others learning and all can achieve better learning outcomes (Abercrombie et al., 2019).

Situated Cognition

Another key component to effective learning is the context in which it is presented. According to the theory of situated cognition, all thinking and learning should be placed within authentic contexts where the distinction between the self and the world is blurred (Slattery, 2013). Real world problems are ill-structured and have complex goals and working within these types of constructs allow students to transfer learning to novel situations (Artino, 2013). In educational settings, subjects are often compartmentalized, and students struggle to make connections between them (Murray-Nseula, 2011), thus presenting gaps in learning. Instruction that allows students to solve real-world problems can be beneficial to students as "the likelihood that knowledge and skills acquired in one course will transfer to real work settings is a function of the similarity of the two environments" (Prince & Felder, 2006, p. 125).

The theory of situated cognition was formally developed by Lave and Wenger (1991) and the authors attempted to provide clarity to the topic of contextualized education. As central to this theory, Lave and Wenger (1991) focused on the idea of legitimate peripheral participation, which is a way of understanding learning and posits that learning happens "in situ" (p. 31) within social environments. Donaldson et al. (2020) expanded upon the idea of legitimate peripheral participation to include three main components: community of practice, authentic context, and embodiment. While the term community of practice was used extensively by Lave and Wenger (1991), the terms embodiment and authentic context are unique to Donaldson et al. (2020).

A community of practice consists of a group of individuals actively interacting in similar activities with similar concepts and in an undergraduate classroom this community may be a group of students as peers with an instructor (Donaldson et al., 2020). Second, Donaldson et al. (2020) also includes the label of "authentic context" (p. 725) to include "knowledge in real-world contexts" (Lave & Wenger, 1991, p. 41) with which participants engage. Importantly, Donaldson et al. (2020) points out that this context can be experienced in two different ways: real or virtual. This virtual perspective on authentic context is amplified by Fraihat et al. (2022) who utilize situated cognition as a theoretical framework for their study which utilizes real-world applications of mathematics in high school geometry. Lastly, embodiment is the term coined by Donaldson et al. (2020) to describe the verbal and kinesthetic activity required in situated cognition by the authors Lave and Wenger (1991).

Active Learning

The American Association for the Advancement of Science (2011) has made a call for teaching and learning in the sciences to be made more active because, as Bennal et al. (2016) has so eloquently stated, "telling is not teaching and listening is not learning" (p. 67). The encouragement for instructors to move towards a more active learning environment has been met with many obstacles, not the least of which is a definition of the term active learning. While many definitions exist, a good description of what is meant by active learning is, "instructional activities involving students in doing things and thinking about what they are doing" (Bonwell & Eison, 1991, p. *iii*). This explanation of active learning points out a key point: activity of the body is different than activity of the mind. Just because an activity is ‘hands-on’ does not mean that it is actively engaging students in the learning process (Anthony, 2017; Bächtold, 2013). While lecture can be one pedagogical approach that can be used, it should not be the exclusive pattern as education is something that teachers should do in collaboration with students (AAAS, 2011).

Over the course of the last 10+ years, there has been a large amount of research performed on the efficacy of active learning techniques. A large-scale meta-analysis was performed by Freeman et al., (2014) that looked at the exam scores and failure rates in STEM courses utilizing passive instruction vs. diverse active learning methodologies. Active learning strategies were found to be correlated with increased performance on assessments in addition to a decrease in the likelihood of failure by a magnitude of 1.5 times regardless of discipline or course level (Freeman et al., 2014). A second meta-analysis by Theobald et al. (2020) examined the specific effect of active learning strategies and their impact on achievement for underrepresented students. These authors found that active learning pedagogical tools in STEM courses decreased the achievement gap in exam scores for underrepresented students by 33%. When the authors controlled for other variables such as class size and course level, there was a reduction in failure rate shown in about half of the studies (Theobald et al., 2020). Other smaller studies have shown that implementation of active learning techniques leads to an increase in student attitude and confidence (Dyer & Elsenpeter, 2018), motivation (Baeten et al., 2013), and increases levels of critical thinking (Birk et al., 2019). These results confirm the statement that, “the most effective teaching has the student fully mentally engaged with suitably challenging, authentic intellectual tasks that embody probing their thinking and offers targeted and timely feedback that guides improvement" (Wieman, 2017, p. 9).

There are many different variations of active learning, but all are considered learner-centered as opposed to instructor-centered and are considered constructivist in nature (Freeman et al., 2014; Prince & Felder, 2006). Each type of pedagogical method has its own research base, history and instructional manual which can often cause confusion (Prince & Felder, 2006). When evaluating a type of instructional methodology, it is helpful to think of different strategies as occupying a specific place along a continuum similar to the graphic in Figure 2.1.

Figure 2.1 *Continuum of Instructor- and Student-centered Classrooms*

Note: Adapted from O'Neill & Mcmahon (2005)

On the left is a purely didactic, teacher-centered classroom and on the right a completely learner-centered classroom where the learner makes all decisions in terms of outcomes (Hays, 2008). Exclusive lecture falls at the left side of the continuum whereas some forms of problem-based learning occupy the right side. Problem-based learning (PBL) often contains few to no lectures and the learning outcomes are largely determined by the students as they utilize very open-ended problems as curricular guides (Hays, 2008; Hopper, 2018). This teaching methodology (PBL) has been criticized by some as carrying a very high cognitive load, lacking guidance, and requiring too much time in the classroom (Hays, 2008; Zahara et al., 2020). While a pedagogical tool located at the ends of the continuum may not be ideal for student learning, there are many other options to explore to provide more active learning for students.

Case-based Learning

As a more directed and focused form of active learning, case-based learning (CBL) shows promise to fulfill the need for minds-on learning in an undergraduate anatomy & physiology classroom. Case-based instruction utilizes stories that have an educational message (Harman et al., 2015) and allows instructors to move from being a "sage on the stage role into a guide on the side" (Heath & Weege, 2017, p. 207). In this type of educational environment, the student's role becomes more active and he or she becomes responsible for engaging with the content. The teacher, on the other hand, moves from being the main disseminator of information to the more passive role of steering the learning in the appropriate direction and providing the scaffolding for the content.

The narrative provided via case-based learning leverages the power of storytelling by providing a mechanism for students to internalize abstract concepts (Hoffer, 2020) and provides for deeper understanding (Bansal & Goyal, 2017; Thistlewaite et al., 2012). Often the stories utilized in CBL integrate science information within social, environmental, and ethical contexts (AAAS, 2011; Bonney, 2015) thus allowing students to integrate knowledge in a more real-world way and motivating them to learn scientific concepts more deeply (Baeten et al., 2013; Labov et al., 2010). This real-world integration of A&P content is listed as a specific learning goal for anatomy and physiology education (HAPS, 2020). Cases do this in a more structured way than problem-based learning as the cases provide rich contextual details and distinct goals throughout the activity (Hopper, 2018; Prince & Felder, 2006). In a typical case, students are provided information to analyze in small segments. For example, in an anatomy & physiology case, the narrative often begins with a person experiencing an injury or ailment. The students are asked pointed questions to draw out the important pieces of information before additional detail is provided in the next section. In this way, the learning is scaffolded for students with each additional piece of information added to what is already know in order to solve a puzzle or answer a question.

The case method of education dates back to the 1870's when Christopher Columbus Landell utilized cases in his courses at Harvard Law School (Hoffer, 2020; Kaddoura, 2011; Kulak & Newton, 2015). In the early 1900's the method started to be used in business and medical education at Edinburgh, Cambridge & Harvard and has since been utilized in many areas of education from teacher training to public administration (Hoffer, 2020; Kulak & Newton, 2015).

The case method of instruction is soundly rooted in constructivist theory as it "facilitates the construction of declarative knowledge as well as the development of analytical…skills" (Hartfield, 2010). Case studies do this by guiding students through the process of being presented with information and then coming to conclusions based on evidence. To develop critical thinking skills, students need to have the decision-making process explicitly defined and modeled, and they require extensive practice in doing so (Holmes et al., 2015). Case-based instruction can provide the structure for the decision-making process to be modeled and practiced as the teacher guides the students through the case. In utilizing this methodology regularly in the classroom, the use of cases helps to promote analytical skills in students (Bansal & Goyal, 2017; Bonney, 2015; Hoffer, 2020) and encourages students to think at the analysis, evaluation, and application levels of Bloom's Taxonomy (Bonney, 2015; Kulak & Newton, 2015; Murray-Nseula, 2011). While lecture only requires students to think at the lower levels of Bloom's Taxonomy and promotes surface learning (Hobbins et al., 2020), "cases facilitate active and reflective learning by exposing learners to complex situations, allowing them to discuss and debate courses of action and providing them with the opportunity to create and discover new ideas" (Herreid et al., 2012).

Over the past ten years, there have been several studies published that looked at the effectiveness of the case study method in different types of environments. There are three studies of note, each showing a slightly different variation of the use of case studies and their effectiveness. In 2017, Bansal & Goyal implemented case study instruction in a physiology course and they measured the effect on learning and student perceptions. They implemented two different cases in two different units and evaluated learning via identical pre-test/post-tests (Bansal & Goyal, 2017). The students (n=150) showed growth that was statistically significant when comparing the pre-test and post-test scores, however, since the pre-test/post-test questions were identical in nature, this effect may be at least partially due to the structure of the assessment. Additionally, students perceived that the content in the cases was easier to learn and that engaging in the case solidified their understanding of the topic. (Bansal & Goyal, 2017).

In a related study, Birk et al. (2019) looked at how the small-scale integration of case studies effected student perceptions in a second semester Anatomy and Physiology course. In this setup, four, 50-minute lectures spaced throughout the semester were substituted with four case studies and at the end of the semester, a Likert scale survey was administered (Birk et al., 2019). There was a negative correlation between perception and socioeconomic status (SES) with the higher SES students more often identifying the case studies as unhelpful and the lower SES students more often identifying the case studies as beneficial (Birk et al., 2019).

Last, Kulak & Newton (2015) published a study that compared CBL to other active learning strategies in an undergraduate biochemistry classroom. The same instructor, teaching four different sections of the course, utilized different active learning strategies in each course and found that the final exam performance was significantly higher for those students that had experienced the case-based activities throughout the semester (Kulak & Newton, 2015). Additionally, the depth of learning was measured, and it was concluded that the utilization of cases prevented surface-level learning compared with other methodologies (Kulak & Newton, 2015).

With the large amount of data that lends support to implementation of this type of instructional methodology, it makes sense for instructors to utilize this strategy in their courses, even if on a small scale. While cases are not the best way to deliver large amounts of raw information (Allchin, 2013; Cliff & Wright, 1996) it is possible to have cases deliver instructional content (Kulak & Newton, 2015). Understanding that cases can deliver content can help ease the anxiety that some instructors feel about sacrificing content by integrating active learning strategies. Different instructors have chosen to implement case studies in various ways and with varying frequency. In lower division courses, it may be helpful to use cases on a regular basis to help students get accustomed to learning from them, but not rely on them as the exclusive teaching methodology as these students may lack the academic experience and maturity required to do so (Cliff & Wright, 1996). Also, in light of social constructivist methodology, it is helpful to have students work in groups as they are completing cases as it assists students in learning through the experiences of others (Baeten et al., 2013; Harman et al., 2015).

Chapter 3: Methodology

Through this study, the researcher investigated one possible answer to the following problem of practice: how to efficiently increase critical thinking skills in an undergraduate anatomy and physiology course. Throughout the literature review, active learning was identified as a required component for progress to be made in this area. Additionally, in applying social constructivism, situated cognition as theoretical frameworks, case studies have been pinpointed to be an effective methodology to employ to resolve the problem of practice. As such, two research questions were identified:

- How does the implementation of active learning in the form of case studies impact critical thinking in my Anatomy & Physiology classroom?
- How do students perceive case studies to influence learning in my Anatomy & Physiology classroom?

For each research question, a null hypothesis was formulated which stated that the treatment group (units) in which case studies were implemented would show no statistical difference from the comparison group (units) taught with traditional, didactic instruction.

Throughout the remainder of this chapter, the setting for the research study will be provided including detailing the demographics of the research participants. This will be followed by a detailed explanation of the procedure that was followed and the methodology utilized for data analysis.

Research Setting

Anatomy and Physiology is taught as a two-semester progression utilizing a well-known textbook (VanPutte & Seeley, 2022) as a student reference. The course meets for three, one-hour lecture sections per week and one, two-hour laboratory. Topics in the first semester course include basic introductory information including anatomical terminology, cell chemistry, and tissues and then transitions to cover the integumentary, skeletal, muscular, and nervous systems, including the special senses. The remaining body systems are covered in the second semester of the course. This study took place in the first semester of the course (Anatomy & Physiology I) and ran from August-December of the year 2022.

At this small liberal arts university in the midwestern United States, students take Anatomy & Physiology as a requirement for many different majors including: biology, pre-medicine, speech-language pathology and audiology, medical laboratory science, nursing, pre-physical therapy, middle childhood education, exercise science, strength & conditioning, and nutrition & dietetics. The average yearly enrollment at this institution is 750 students. While a student will occasionally take the course only to fulfill a general education requirement, most frequently students fall within one of the listed majors and are often in their first or second year of their undergraduate experience. Importantly, some of the students entering the course in the fall have had a full year of General Inorganic Chemistry prior to this A&P course, while other students have little to no undergraduate-level science instruction.

Participants in the Study

Before the study commenced, the study methodology was submitted to two Institutional Review Boards (IRB) for approval to ensure that the rights and welfare of the students participating were being adequately protected. Both IRB boards approved the study as Exempt from review (USC #Pro00122731). Because this study was considered exempt, students were not required to consent to participate as they were completing the activities as part of the daily tasks of the course.

In the fall of 2022, all students in the course (*n* = 50) participated in the study. Of the students enrolled in the course, 2 were classified as seniors, 5 as juniors, 33 as sophomores, and 10 as first-year students. Additionally. the students represented a wide range of majors as noted in Table 3.1.

Table 3.1 *Fall 2022 Student Make-up – Anatomy & Physiology I*

Major	Senior	Junior	Sophomore	First-year
Biology	0	0	3	1
Exercise Science	1	2	13	0
Middle Childhood Education	0	1	0	0
Medical Laboratory Science	0	0	0	1
Nursing	0	0	2	6
Nutrition & Dietetics	0	0	9	0
Pre-Physical Therapy	0	0	4	2
Speech-Language Pathology & Audiology	1	1	0	0
Strength & Conditioning	0	1	2	0

Of the students enrolled in Anatomy & Physiology I, 13 of them had successfully completed both General Inorganic Chemistry I and II, 4 had completed General

Inorganic Chemistry I, 23 had completed a general education science course (Experiential Chemistry, The Biological World, The Physical World), and 10 had no undergraduate science instruction prior to the course. These demographic characteristics were collected from the students on the first day of class.

Research Methods

Throughout the semester, nine different units are covered in Anatomy & Physiology I: Introduction to A&P, Chemical Basis of Life, Cell Biology, Tissues, Integumentary System, Skeletal System, Muscular System, Nervous Tissue, and Special Senses. For each unit, pages of the textbook (VanPutte & Seely, 2022) are assigned for the students to read, and this is detailed in the syllabus, distributed at the beginning of the semester. All content covered in the course, regardless of teaching methodology, is detailed in the textbook. Four of the units were taught in a traditional, didactic method, consisting mostly of lecture while the other five had didactic instruction with the addition of a case study. In the units where a case study was utilized, the content covered in the case study was taught utilizing a case study and was not intentionally covered in lecture. As the semester progressed, several of the cases covered a very wide variety of content so in the later cases there was some double coverage of content: both didactically and via a case study. In some of the earlier units, there was not additional time spent with the implementation of case studies, however, in the later units a bit of additional time was required. Regardless of the teaching methodology, all course content was explained in the assigned textbook readings.

To evaluate the critical thinking learning gains of students, several different measures were utilized and are summarized in Table 3.2. First, all students completed a baseline critical thinking score was obtained at the beginning of the semester by the Cornell Critical Thinking Test (CCTT) – Level Z. This assessment was then repeated at the end of the semester to determine overall critical thinking gains. Both the pre-test and post-test were administered online via Moodle, the Learning Management System utilized by the University in which I teach, and students received participation points for completing the assessment.

The CCTT was developed by Robert H. Ennis and colleagues at both Cornell University and The University of Illinois and measures the following areas of general critical thinking ability: induction, deduction, observation, credibility, assumptions, and meaning (Ennis et al., 2005). The assessment has two different levels, X and Z, each intended for a different audience. Form Z is designed for “advanced and gifted high school students, college students, graduate students, and other adults” (Ennis et al., 2005, p. 1) and consists of 52 multiple-choice items broken down into seven different sections containing 4-13 questions. Each section of the test measures a different component of critical thinking including: deduction, meaning & fallacies, observation & credibility of sources, induction (hypothesis testing), induction (planning experiments), definition and assumption identification, and assumption identification.

The test developers have assembled data from 23 studies investigating the construct validity of the CCTT-Z and found that the average correlation was 0.55, indicating a strong positive relationship between the total score results of the CCTT-Z and tests such as Watson-Glaser Critical Thinking Appraisal, Statistical Reasoning Test, the ACT, LSAT, SAT, among others (Ennis et al., 2005). This positive correlation in construct validity indicates that the CCTT-Z measures what it sets out to measure and that the "scores serve a useful purpose" (Creswell & Creswell, 2018, p. 153). All validity testing has been done utilizing the entirety of the test and not the individual sections (part-scores), thus the overall score was utilized in this study as a critical thinking analysis tool.

Table 3.2 *Summary of Research Question and Data Collection/Analysis*

Research Question	Data Collection Techniques	Data Analysis
1. How does the implementation of active learning in the form of case studies impact critical thinking in my Anatomy & Physiology classroom?	Quantitative: • Cornell Critical Thinking Test (CCTT) – Level Z • Critical thinking exam question scores • End-of-chapter assignments – graded with rubric	• Descriptive statistics • t-test • Cohen's *d*
2. How do students perceive the case studies assist or hinder their learning in my Anatomy & Physiology classroom?	Quantitative: • Student Assessment of Learning Gains (SALG) questionnaire	• Mean, median, mode, standard deviation

A second measure compared the difference in critical thinking scores between the comparison and experimental method. For each of the three exams given over the course of the semester, critical thinking multiple-choice questions were selected from the VanPutte & Seely (2022) exam question bank: four questions labelled as assessing the “Apply” level of Bloom’s and four labelled as “Analyze”. Two of the four “Apply” questions covered content that was taught in a traditional (lecture) method and two covered material taught utilizing case studies. The same procedure was utilized for the “Analyze” questions. To verify the level of Bloom’s Taxonomy that was being assessed, the questions were analyzed using the Blooming Anatomy Tool (see Appendix A). The Blooming Anatomy Tool (BAT) was originally developed to assist instructors in classifying the cognitive level of multiple-choice questions in the anatomical sciences by highlighting characteristics of each cognitive level, specifically in this content area (Thompson & O’Loughlin, 2015). If there was a discrepancy between the textbook-scored level and the level identified utilizing the BAT, the BAT level was employed. The multiple-choice questions for the first exam are detailed in Appendix B.

The scores on these questions were compared to determine the effect of case-based versus traditional didactic instruction on critical thinking skills. After each exam was graded the scores for each individual student were recorded into a chart (see Appendix C) and detailed the number of multiple-choice questions that were answered correctly in each category: “Apply” questions from traditional instruction, “Analyze” questions from traditional instruction, “Apply” questions from case-based instruction, and “Analyze” questions from case-based instruction. Each student was given a random number to maintain confidentiality.

As a last category of data collection, students were asked, at the end of each unit, to answer a real-life, critical-thinking question as a homework assignment. Student responses were then evaluated with a rubric based upon one created by the Enhancing

Learning by Improving Process Skills in STEM (ELIPSS) Project, funded by the National Science Foundation. This group was responsible for creating validated rubrics that can be used to assess evidence of process skills in both student interactions and written work (Reynders et al., 2020). The critical thinking rubric (see Appendix D) evaluates five major categories of the skill and has been tested for validity, utility, and reliability (Reynders et al., 2020). In the current study, the categories of evaluating, analyzing, and synthesizing were utilized in critical thinking assessment.

For the content taught via cases, the students were asked to write a paragraph summarizing the main points of the case by answering four questions (see Appendix E). These responses were then scored utilizing the rubric in Appendix F, which is a shortened version of the ELIPSS rubric. For the units that were taught only didactically, students were asked to read a short case vignette in the textbook and answer critical thinking questions related to the content presented in the case. Most chapters in the VanPutte & Seely (2022) textbook contain at least one of these case vignettes, termed a case study by the textbook authors. They case studies are, however, much shorter and contain much less detail than the case studies completed in class. An example of one of these cases is shown in Appendix H. This assignment was given as homework at the end of each chapter taught didactically and was scored utilizing the same rubric (see Appendix F).

In addition to direct measures of learning, students' perception of learning using the case studies was evaluated by the Student Assessment of Learning Gains (SALG) survey. This survey, originally delivered online and developed by Elaine Seymour in

1997, is standardized, but instructors can tailor the assessment to their class structure (http://www.salgsite.org). For the purposes of this study, the survey consisted of three main questions in which students were first asked to evaluate the learning gained in each case study presented throughout the semester. The survey then asked students to evaluate their perception of learning when taught via case-based instruction, traditional didactic instruction, course readings, and laboratory activities. Last, the students were asked to evaluate the effectiveness of the course activities in relating to everyday life. The questions were based on a similar study done by Bonney (2015). In this study, the SALG survey was administered via paper and pencil (see Appendix I) during the last week of the semester, with the instructor out of the room. A student was asked to collect the surveys and deliver them to the instructor's office once all students had completed the survey. All responses were anonymous, and no record was kept of students who did or did not complete the survey.

Procedure

To begin the research study, the objectives for each unit in the course were identified utilizing learning outcomes identified as important by the Human Anatomy and Physiology Society (HAPS, 2019). Five of the ten units were then selected to be taught incorporating case study methodology. Those units included: Chemical Basis of Life, Cell Biology, Skeletal System, Muscular System, and Nervous Tissue. In each of the five units listed, one to two days of lecture were substituted for a case study covering the objectives planned for the day. In the traditionally taught units, the information was presented only via lecture. While students were provided PowerPoints and readings for the material covered in the case studies, no traditional lecture instruction was provided for this content.

All case studies were selected from the National Center for Case Study Teaching in Science (NCCSTS) and were chosen based on alignment with the learning objectives covered. The NCCSTS case studies were originally curated by the University at Buffalo, funded by grants from the National Science Foundation, The Pew Charitable Trusts, and the U.S. Department of Education, however, the collection is currently managed by the National Science Teaching Association (n.d.). Each case study contains a student worksheet and a teacher guide, including an answer sheet. The cases utilized in this course are listed in Table 3.3 and are of varying lengths. Some of the cases were completed in their entirety while for others, only the parts that correlated to the learning objectives were completed.

Table 3.3 *Case Studies Utilized and Objectives Covered*

Unit Name	Case Study Name	Case Study Author	Objectives Targeted
Chemical Basis of Life	The Biochemistry of Curly and Straight Hair	W. Gibson	Module C, 1, 3 Module C, 2, 1 Module C, 2, 2
Cell Biology	Little Girl Lost: A Case Study on Defective Cellular Organelles	T.Y. Hudson	Module C, 10, 1 Module C, 10, 2
Skeletal System	Bones, Stones, Groans and Moans: A Calcium Story	J.K. Jellyman & H.J. Ticheli	Module F, 5, 4 Module F, 5, 5
Muscular System	All or Nothing: A Case Study in Muscle Contraction	R.T. Neumann, C.J. Quinn, B.A. Whitaker, S.T. Woyton & B.N. Harris	Module G, 4, 1 Module G, 4, 2 Module G, 4, 3
Nervous Physiology	Bad Fish: Human Anatomy & Physiology Edition	J.A. Hewlett	Module H, 7, 2 Module H, 7, 3 Module H, 7, 4

Each case study in utilized in the course was analyzed to determine the level of thinking that was required to complete the activity. To do this, each question in the case study was evaluated utilizing the Blooming Anatomy Tool (see Appendix A) and questions were classified into the first four levels of Bloom's Taxonomy – Knowledge through Analysis. The different cases utilized contained a broad range of questioning levels as indicated in Table 3.4

Table 3.4 *Case Studies Utilized and Bloom's Taxonomy*

Case Study Name	Knowledge	Comprehension	Application	Analysis
The Biochemistry of Curly and Straight Hair	30.0%	30.0%	20.0%	20.0%
Little Girl Lost: A Case Study on Defective Cellular Organelles	36.8%	26.3%	26.3%	10.5%
Bones, Stones, Groans and Moans: A Calcium Story	21.0%	26.3%	36.8%	15.8%
All or Nothing: A Case Study in Muscle Contraction	25.0%	25.0%	6.3%	43.7%
Bad Fish: Human Anatomy & Physiology Edition	13.3%	40.0%	13.3%	33.3%

In the first week of the semester, 12 formal cooperative groups were established by the instructor. Formal cooperative groups are long-term associations with a consistent membership that engage in deliberate conversation to work through a problem (Abercrombie et al., 2019; Faust & Paulson, 1998). These groups remained intact throughout the semester and were assigned utilizing declared major to create heterogeneous groups of four to five students. While there is a variation of opinion regarding the best methodology for grouping students, some research has shown that heterogeneous grouping is more beneficial, especially if students are grouped based on different learning perspectives (Kanika et al., 2022) or different levels of competency in the subject (Donovan et al., 2018). Students in Anatomy & Physiology I have varying levels of science background when entering the course and this can contribute to a large disparity of preparation, especially in chemistry. Some students enter the course as sophomores having completed a full year of General Inorganic Chemistry (Biology, Pre-Physical Therapy, and Nutrition & Dietetics majors) and others have had either no college science courses (Nursing majors) or only one general education science course (Exercise Science, Strength & Conditioning, Speech-Language Pathology & Audiology, and Middle Childhood Education majors). Because this variation and lack of preparation can be a barrier for some in the course, students were grouped heterogeneously based on declared major. At least one student who had taken the full General Inorganic Chemistry sequence was placed in each group and the Nursing majors were randomly distributed throughout the groups.

Before cases were implemented in the class, a portion of a class period was spent instructing students on the benefits and strategies of working in groups (see Figure 3.1). Specific instruction in how to work in groups was provided and groups were given a short activity to get to know each other. Group work instruction entailed explaining the different roles that each student would take during the case study activities: Facilitator, Recorder, Spokesperson, Reader. Groups that contained five students had the additional role of Encourager. The students were instructed to switch roles for each of the five cases throughout the semester.

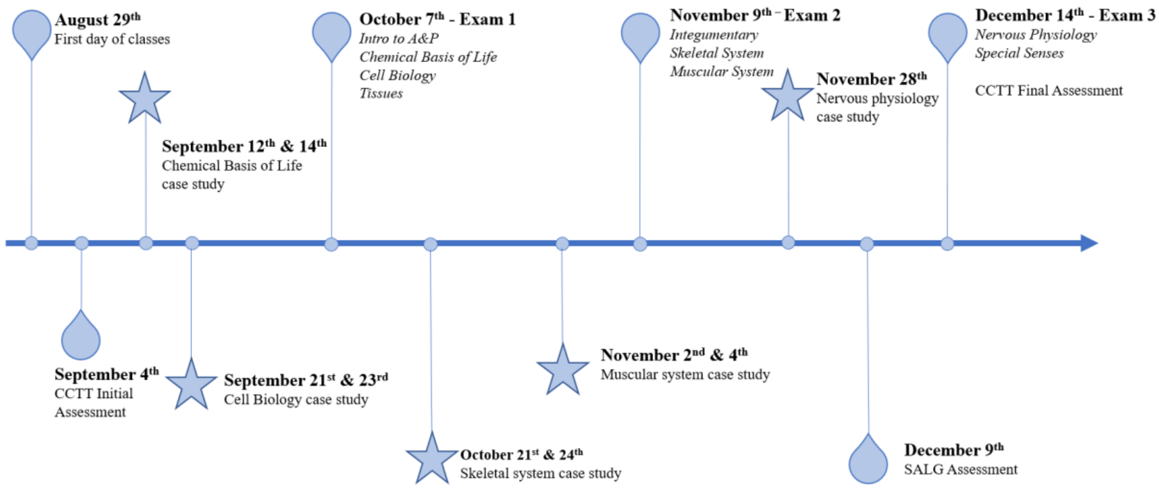

Figure 3.1 *Timeline of Study – Fall 2022*

Note: Star-shaped markers indicate a unit with a case study.

On the day of a case study, the instructor briefly met with the class as a whole for instructions and attendance and then the students broke into their pre-assigned groups and the case study was distributed. The methodology implemented for each of the case studies is the interrupted design where students work on a portion of the case and then meet back as a whole for group discussion before moving on to subsequent sections of the case study. In this way, students can work with manageable amounts of information at one time and are not as easily overwhelmed. Additionally, this allows the instructor to identify any misconceptions as the students work through the case. After the end of the class session, students were provided with a homework assignment that required them to summarize the main concepts presented in the case study. These assignments were turned in on Moodle (our Learning Management System) and were scored with an ELIPSS-based rubric.

For the units that were taught didactically, a similar homework assignment was developed that required students to summarize and synthesize information from that unit. An ELIPSS-based rubric was developed for that question and responses were scored and recorded. Both the case-based homework assignments and didactic homework assignments were termed End of Chapter assignments (EOCs) and were coded as such in Moodle and in the gradebook.

The three exams took place on October 7th, November 9th, and December 14th, each covering two to four units of material. Each exam consisted of 50 multiple-choice questions and three to four short answer questions. The scores on the eight selected multiple-choice critical thinking questions were recorded as well as the overall exam score for each student (see Appendix C).

At the end of the semester, the students took the Student Assessment of Learning Goals questionnaire in class. This survey assessed the student's perception of learning utilizing the case studies compared to other course instruction methodologies. The number of responses were recorded, but each survey was submitted anonymously, and the instructor was unaware of who did or did not turn in the survey.

Data Analysis

To evaluate the efficacy of case studies to increase critical thinking in an Anatomy and Physiology course, several data analysis tools were utilized. First, pre-course and post-course scores on the Cornell Critical Thinking Test (CCTT) were analyzed via descriptive statistics and a paired t-test to determine the degree to which general critical thinking improved over the course of the semester. The t-test evaluated the differences in the mean critical thinking score between the beginning and end of the semester. Because of the lack of validity testing of the part-scores of the CCTT-Z, the overall score was used in analysis.

To determine the effect of case study instruction versus traditional instruction on discipline-specific critical thinking skills, two different sets of scores were compared: homework summaries and exam data. The homework summary scores from each unit were compiled, sorted into teaching methodology, and analyzed using a paired t-test to determine if the teaching style influenced the level of critical thinking shown on the homework summaries. Similarly, scores from selected multiple-choice questions were compiled, sorted into teaching methodology, and analyzed using both a paired t-test and a Cohen's *d* to analyze effect size. While the t-test determined the differences in means between groups of scores, the Cohen's *d* determined the strength of this difference by also factoring in the standard deviation of the data set. Overall exam scores were analyzed and further broken down based on several student factors including gender and level of chemistry preparation.

The results from the SALG survey were tabulated and the following results were reported: number of responses (*n*), mean, mode, and standard deviation. This data provided information about how the students perceived individual case studies as well as overall teaching methodologies to impact learning.

Validity Evidence

The End of Chapter Assignments (EOCs) were assessed utilizing a rubric based on a rubric created by the Enhancing Learning by Improving Process Skills in STEM (ELIPSS)

Project. This project was funded by the National Science Foundation and was responsible for creating validated rubrics that can be used to assess evidence of process skills in both student interactions and written work (Reynders et al., 2020). While the rubric itself has been tested for validity, utility, and reliability (Reynders et al., 2020), it is important the individual scoring the responses is accurately utilizing the rubric. Ideally in this study, a second individual would have scored a set number of responses to ensure that the rubric was accurate and able to produce valid results. However, since there is only one instructor at the institution with expertise in Anatomy & Physiology, this was not a possibility. Instead, a very clearly defined rubric helped to assess the critical thinking skills of each individual student.

For each assignment, three questions were asked of the students. In the first question, the students needed to identify the pieces of information in the case that were necessary to find the answer to the problem that the patient was experiencing. This question correlated to the "evaluation" level of thinking in the ELIPSS rubric. In the second question, the students were asked how the information in question 1 would be used to answer the question or solve the problem that the case was attempting to answer. This was evaluated by the "analysis" level of thinking in the ELIPSS rubric. And last, the students were asked to put all the information together and answer the question or solve the problem that the case study posed utilizing the information they provided in questions 1 and 2. This was then evaluated by the "synthesis" level of the rubric.

To provide as much consistency as possible in grading, a sample answer was written by the instructor. Students were then graded according to the level of agreement that their answer had with the instructor answer. Students received full credit (five points) if their answer contained all portions of the instructor answer. They received four points if they were missing one minor portion in their answer and three points if they partially provided the correct answer. Two points were earned if the student was missing several key components and one point was earned if the student answer the question but was incorrect. Zero points were earned if the question was left unanswered.

An example is given below utilizing the case study EOC from chapter 6 titled "Bones, Stones, Groans and Moans: A Calcium Story" which contained content on bone physiology and calcium homeostasis. The rubric utilized for this specific End of Chapter assignment along with the instructor answers are located in Appendix G. Tables 3.5 and 3.6 show sample responses from two different students and the scoring for each utilizing the sample answers in Appendix G. The boxes highlighted in light blue designate the score given for that part of the assignment.

Table 3.5 *Scoring of EOC Chapter 6 – Example #1*

Student Response	5 points	4 points	3 points	2 points	1 point
The main points of data that we need to know are about the hormones and what they do in the body. Along with that you need to know how the hormones decrease and increase the blood calcium levels and the mechanisms in which they do it. We also need to know the areas of the body which are being affected such as the thyroid, kidneys, bone, and parathyroid.	Extensively determined the relevance of information that might be used to support a conclusion or an argument.	Missing one portion of the answer.	Partially determined the relevance of information that might be used to support a conclusion or argument.	Missing several elements of the answer.	Minimally determined the relevance of information that might be used to support a conclusion or argument.
Through the knowledge of the negative feedback mechanism, we are able to relate how the body maintains blood calcium levels through the use of hormones. Also, to show what triggers the release of the hormones and what they act upon.	Accurately interpreted information to determine meaning and to extract relevant evidence.	Missing one portion of the answer.	Interpreted information to determine meaning and to extract relevant evidence with some errors.	Missing several elements of the answer.	Inaccurately interpreted information to determine meaning and to extract relevant evidence.
When blood calcium levels are elevated, you will notice how the thyroid is stimulated to then release calcitonin. When the calcitonin acts upon the osteoblast it causes them to use the calcium in the blood to build up bone. By using up the extra calcium in the blood the levels then return to normal. Calcitonin also works on the kidneys to decrease calcium reabsorption meaning that more calcium is able to be excreted in the urine.	Accurately connected or integrated information to support an argument or reach a conclusion.	Missing one portion of the answer.	Connected or integrated information to support an argument or reach a conclusion with some errors.	Missing several elements of the answer.	Inaccurately connected or integrated information to support an argument or reach a conclusion.

Table 3.6 *Scoring of EOC Chapter 6 – Example #2*

Student Response	5 points	4 points	3 points	2 points	1 point
Calcium levels and how they negatively impact our bodies if they're too high. Calcium plays an important role in our bodies and too much of it can cause issues.	Extensively determined the relevance of information that might be used to support a conclusion or an argument.	Missing one portion of the answer.	Partially determined the relevance of information that might be used to support a conclusion or argument.	Missing several elements of the answer.	Minimally determined the relevance of information that might be used to support a conclusion or argument.
Her calcium levels were too high this was caused because bone resorption goes down and the release of calcium goes down as well.	Accurately interpreted information to determine meaning and to extract relevant evidence.	Missing one portion of the answer.	Interpreted information to determine meaning and to extract relevant evidence with some errors.	Missing several elements of the answer.	Inaccurately interpreted information to determine meaning and to extract relevant evidence.
This helps because knowing that her levels were too high and why they were too high helps determine what can be done to help prevent from this issue continuing.	Accurately connected or integrated information to support an argument or reach a conclusion.	Missing one portion of the answer.	Connected or integrated information to support an argument or reach a conclusion with some errors.	Missing several elements of the answer.	Inaccurately connected or integrated information to support an argument or reach a conclusion.

Chapter 4: Study Findings

The researcher conducted this study to attempt to solve the following problem of practice: How can critical thinking skills efficiently be increased in an undergraduate Anatomy & Physiology classroom? Chapter 4 presents the findings of the current study utilizing case studies as an answer to this problem of practice. The following two research questions were investigated:

1. How does the implementation of active learning in the form of case studies impact critical thinking in my Anatomy & Physiology classroom?
2. How do students perceive case studies to influence learning in my Anatomy & Physiology classroom?

The sample for this study included all students enrolled in BIO 230 – Anatomy and Physiology I in the fall of 2022. It was hypothesized that the incorporation of case study instruction would increase both critical thinking and the perception of learning in comparison to lecture-only instruction. The data in this section is categorized by corresponding research question. Three different types of quantitative data were collected to provide insight to the impact on critical thinking (research question #1) and one type of quantitative measure was collected to address student perceptions of learning (research question #2).

Research Question 1: Impact on Critical Thinking

Cornell Critical Thinking Test – Level Z

The Cornell Critical Thinking Test – Level Z (CCTT-Z) was administered at the beginning (September) and end (December) of the fall semester to ascertain the level of general critical thinking ability and potential growth over the span of the course. This test was administered via Moodle, the institution's learning management system. In September all students completed the assessment (n=50) however in December, multiple students did not complete the CCTT instrument (n=43). The critical thinking assessment contains 52 multiple-choice questions and is scored by the number of questions answered correctly. The results of both administrations are shown below in Figure 4.1. In September, the average score on the assessment was a 23.4 with a standard deviation of 5.05. In December, the average score was 22.6 with a standard deviation of 4.85. The questions remained the same between the two administrations.

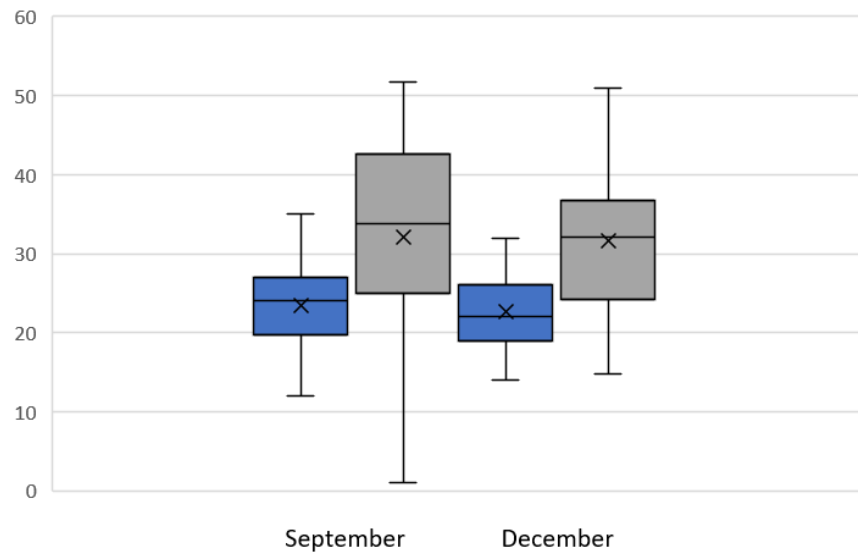

Figure 4.1 *Cornell Critical Thinking Scores and Time Spent on Assessment*

Note: Plots in blue indicate scores on each test administration and indicate the number of questions correct out of 52 questions. The plots in grey indicate the number of minutes the students spent on the assessment in minutes.

As the assessment was administered via Moodle, it was possible to record the amount of time that each student worked on the assignment. The maximum number of minutes allowed on the CCTT is 50 minutes, however since the students needed to read a lengthy set of instructions before beginning and the timer started as soon as the assignment was opened, a maximum allotment of 51 minutes was allotted for each administration. The average time spent on the assessment in September was 32.14 minutes with a standard deviation of 12.9, while the average time spent on the December administration was 31.57 minutes with a standard deviation of 9.9.

It is interesting to note that the average CCTT-Z score did decrease slightly between the September and December administrations. However, looking at individual student data may provide some insight. Of the 43 students who took both administrations of the exam, 19 of those students increased their score from the first to the second round. Of the 24 whose scores decreased in December, 10 of those students spent less than half of the allotted time on the exam, spending less than 25 minutes total on this reading-intensive exam.

To statistically assess this data, the CCTT scores were compared from the beginning to the end of the semester utilizing a paired t-test. The significance for the study was set at p=0.05 and the results are shown in Table 4.1. The overall significance for all students when comparing pre- and post-test scores was 0.06 which is above the accepted p=0.05 value. In addition, two variables were isolated to determine if specific groups of students were impacted differently: gender and level of chemistry preparation. Those students who had not had a previous college-level chemistry course were compared with students who had taken a previous course in chemistry. When isolating each of the variables, none showed any statistical significance.

Table 4.1 *Comparisons of Pre-test and Post-test CCTT Scores*

	Pre-test average	Post-test average	p value
all	23.4	22.6	0.06
male only	24.0	22.9	0.06
female only	22.8	21.3	0.11
no chemistry	22.6	22.1	0.08
chemistry	24.8	23.5	0.06

Critical Thinking Exam Questions

The second data set collected to assess critical thinking was in the form of selected multiple-choice test questions on the three exams administered in the course.

For each of the three exams, eight multiple-choice questions were selected for analysis: four covering information taught via traditional (didactic) methods and four covering information taught utilizing case studies. Within each teaching methodology, two questions were selected that were coded at the Bloom's Taxonomy level of "Apply" and two were selected that measured the "Analyze" level (see Table 4.2), both representing critical thinking. Exam questions were obtained from the textbook publisher (VanPutte & Seeley, 2022) and the questions that appeared on Exam #1 are in located in Appendix B.

Table 4.2 *Summary of Exam Data Collected*

Traditional Instruction Questions			Case-Based Instruction Questions		
Apply 2 possible	Analyze 2 possible	Total 4 possible	Apply 2 possible	Analyze 2 possible	Total 4 possible

The total number of correct answers in each category were tabulated and compared. Table 4.3 displays the average number of questions correct in each category based on teaching methodology and Figure 4.2 displays a visual representation of student scores, grouped by exam, teaching methodology, and level of Bloom's Taxonomy that was assessed. It is interesting to note that the questions assessing material covered by case-based instruction were answered correctly more often than those assessing material covered in a traditional, didactic method. While the "Apply" skill is coded in Bloom's Taxonomy at a lower cognitive level, students often showed the greatest positive improvement in the "Analyze" skill level when comparing the two teaching methodologies.

Table 4.3 *Number of Multiple-Choice Questions Correct*

	Traditional			Case based		
	Apply	Analyze	Total	Apply	Analyze	Total
Exam #1	0.94	1.12	2.06	0.86	1.34	2.2
Exam #2	1.34	1.06	2.4	1.34	1.38	2.72
Exam #3	0.92	0.7	1.62	1.54	1.08	2.62

Note: The maximum possible is two for Apply and Analyze and four for Total.

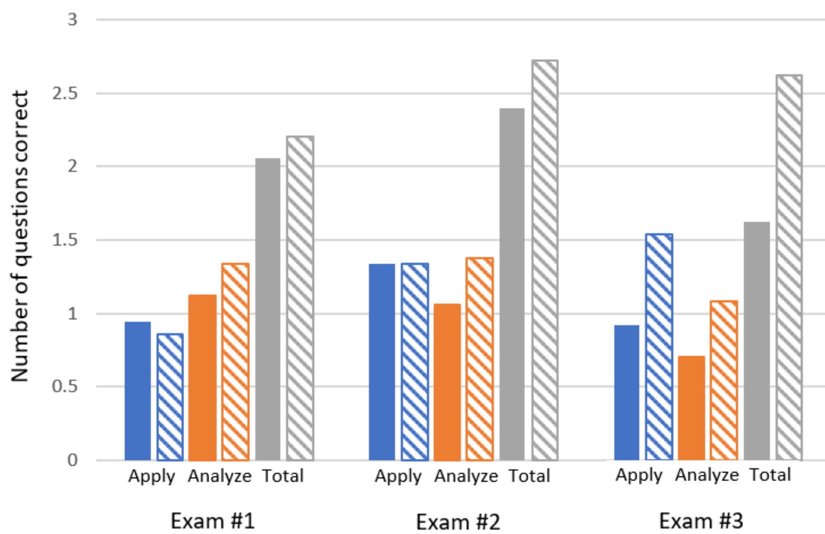

Figure 4.2 *Comparison of Instruction Methodology and Exam Performance*

Note: Solid bars represent questions covering information taught via traditional instruction while striped bars represent case-based instruction.

On each of the unit exams, a paired t-test was utilized to discover differences in the mean between items covering information taught utilizing traditional instruction and those taught via cases. Overall differences were analyzed utilizing whole-class data and then two different factors (gender and level of chemistry preparedness) were analyzed independently. Table 4.4 shows p-values for each of the different analysis types.

Comparing the first two exams with the third yields some interesting trends. On the first two exams, the only significant difference in the "Apply" category when comparing teaching methodologies was found when comparing those students with no college chemistry background, showing that students with no formal chemistry instruction at the college level had a significant increase in learning when taught via case studies compared with lecture instruction. Additionally, there were several points of significance when comparing the questions asked at the "Analyze" skill level. There was an overall positive difference when comparing all students as well as some pockets of students (males only, females only, no chemistry) that answered the questions more effectively when material was presented in a case-based fashion. Interestingly, in Exam #3 all students and sub-categories of students taught with cases showed an increase in scores compared with students taught by traditional instruction.

Table 4.4 *Multiple-Choice Score Comparisons – p-values*

	Exam 1			Exam 2			Exam 3		
	Apply	Analyze	Total	Apply	Analyze	Total	Apply	Analyze	Total
All students	0.24	0.03*	0.18	0.5	0.02*	0.04*	0.00009*	0.0003*	0.0003*
Males only	0.16	0.02*	0.19	0.41	0.07	0.12	0.01*	0.02*	0.0006*
Females only	0.5	0.3	0.35	0.38	0.04*	0.1	0.004*	0.002*	0.0003*
No chemistry	0.02*	0.06	0.36	0.25	0.02*	0.1	0.0005*	0.004*	0.00004*
Chemistry	0.05	0.13	0.04*	0.19	0.15	0.12	0.04*	0.02*	0.004*

Note: (*) denotes values for which the null hypothesis is rejected ($p < 0.05$).

To determine the size of the effect that case-based instruction had on exam scores, a Cohen's *d* was calculated for the overall testing data as well as subgroups and the results are shown in Table 4.5. The effect size calculated by using a Cohen's d is "based on the difference between observations, divided by the standard deviation of these observations" (Lakens, 2013, p. 2). While scores on a Cohen's *d* value can range from zero to infinity, Cohen (1988) chose to label the effect size as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$). Negative values in Table 4.5 indicate higher mean scores on the questions taught via traditional instruction while positive numbers indicate higher average scores on questions covering content taught via cases. A similar yet different pattern is revealed when analyzing the data with this tool. Over the course of the three exams, students began to accurately answer the case-based questions at higher proficiency than the questions covering content taught by traditional instruction. However, by looking at both the *p*-values and the Cohen's *d* values, more clarity can be given to the results. While the *p*-values in several subcategories (Table 4.4) indicated a significance in the mean between groups the effect size was not considered large when utilizing Cohen's *d* (e.g. Exam #2, No Chemistry). This indicates that while the means may be significantly different, the range of scores between the control and experimental group were highly variable.

Several of the subgroups in Exams #1 and #2 showed a significant effect size in the Analyze category of questioning when evaluating the data with Cohen's *d.* For the first exam, there was a significant effect size with all students combined as well as those students who did not have prior undergraduate chemistry before taking Anatomy & Physiology I. This indicates that the case study method of instruction was correlated with better exam performance with this level of questioning for these students. In Exam 2, the effect size was almost exclusively large at the Analyze level of questioning as well. As the data is analyzed over the course of the semester, there was an increase in practical significance for case methodology showing an increased correlation with exam performance as the semester progressed. By the end of the semester, the effect size increased for the Apply level of questioning as well as the Analyze level.

Table 4.5 *Multiple-Choice Score Comparisons – Cohen's d*

	Exam 1			Exam 2			Exam 3		
	Apply	Analyze	Total	Apply	Analyze	Total	Apply	Analyze	Total
All students	-0.67	1.05**	0.41	0	2.33**	0.68*	0.71*	0.84**	1.43**
Males only	-0.74	0.49	0.62*	0.03	2.07**	0.57*	2.23**	0.79*	1.22**
Females only	0	0.53*	0.29	-0.12	5.67**	1.19**	1.65**	0.86**	1.65**
No chemistry	-1.50	2.33**	-0.18	-0.25	0.57*	0.33	3.53**	0.77*	1.30**
Chemistry	1.88**	0.62*	1.15**	0.67*	3.00**	0.82**	1.00**	1.03**	1.88**

Note: (*) denotes values with a medium effect; (**) denotes a large effect size (Cohen, 1988).

End of Chapter Assignments (EOCs)

The third category of data collected to assess growth in critical thinking was a set of homework assignments termed End of Chapter assignments (EOCs). EOCs were a different based on the teaching methodology used for the content in that chapter. If the content was delivered via case-based instruction, students were asked to answer a set of questions that analyzed their critical thinking skills related to the case (see Appendix E). In the other chapters where the content was covered didactically, the EOC would entail reading a short case and answering questions similar to those covered in the case-based EOCs. An example "case" utilized for didactic units is shown in Appendix H. The rubric utilized for all EOC assignments, both case-base and didactic, is shown in Appendix F. The scores for each student were recorded and the topic of the case study, average percentage attained, and standard deviation of the raw scores are shown below in Table 4.6.

Table 4.6 *End of Chapter Assignment Data*

	EOC #1	EOC #2	EOC #3	EOC #4	EOC #5	EOC #6	EOC #7	EOC #8	EOC #9
Topic	Intro to A&P	Bio-chemistry	Cell parts	Tissues	Skin	Bone	Muscle	Nervous	Senses
Average %	48.0%	66.3%	75.0%	66.7%	87.5%	86.7%	86.2%	84.7%	88.7%
Standard deviation	3.2	3.4	4.2	3.4	2.4	2.5	2.4	2.0	2.5

Note: Columns shaded blue indicate chapters taught via case-study methodology.

The modified ELIPSS rubric that was utilized to assess the EOC assignments included three critical thinking categories: evaluating, analyzing, and synthesizing. Students received between 1-5 points in each category based on their responses to the questions asked. This data was collected for each student, but when analyzed no significant difference in scores between categories was observed, hence the category data is not listed here.

Students generally increased in their scores on the EOCs as the semester proceeded, regardless of teaching methodology. Additionally, the standard deviation also generally decreased throughout the year, meaning that students were not only scoring higher on the EOCs but the variability in scores decreased as well.

Summary

The Cornell Critical Thinking Test – Level Z is a measure of general critical thinking skills (Ennis et al., 2005) and the students did not show a significant change in score between the beginning and end of the course. The other measures of critical thinking including the exam questions and EOC assignments were content-specific and showed a variety of results. While students performed better on multiple-choice questions when the content was covered via case-based methodology, there was not a parallel result when students completed more open-ended questions in the EOC assignments.

Research Question 2: Student Perception of Learning

Student perception of learning via different learning methodologies was measured by employing the Student Assessment of Learning Gains (SALG) survey during the last week of the semester. This Likert-style survey was completed anonymously in class and the questions are provided in Appendix I. The results were analyzed quantitatively.

Forty-four of the 50 possible students completed this optional, paper survey anonymously. The first question asked about the effectiveness of each specific case study in helping students learn the topic covered in that activity. Students responded to Likert-style questions with answer options ranging from “Helped a great amount” to “Provided no help”. Students could also indicate that they did not remember the specific case study. Students selecting this option ranged from 0-3 students, varying with the case study in question. Figure 4.3 shows the percentage of students selecting each of the survey answer options but does not include those students who could not remember the specific case. While the percentage of students perceiving individual cases to help a great amount and a small amount were different based on the cases employed, the number of students selecting that the cases provided good or moderate levels of help stayed relatively consistent regardless of the case in question. Interestingly, while the muscular system case was cited by the most students as providing a great amount of help, it was also the case that was identified by the largest number of students as providing no help.

The SALG survey then asked students to rate, using the same scale, how each of the major learning methodologies utilized in the course contributed to their learning. The four major strategies assessed were the textbook, lecture, case studies, and lab exercises. Students had the option to also choose "did not complete" if they did not utilize any of the methodologies listed. This option was developed specifically for the textbook question, as in the past students have reported not utilizing the textbook throughout the course. The percentages of students reporting in each category are represented in Figure 4.4.

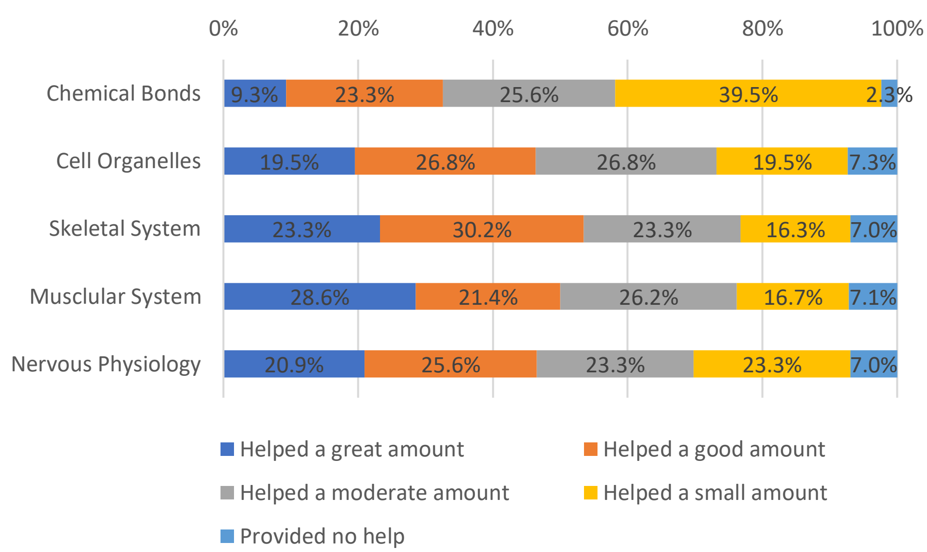

Figure 4.3 *Student Perception of Learning Utilizing Specific Case Studies*

In comparing these four teaching methodologies, students perceived to learn the most when listening to lectures and completing lab activities and no students rated either methodology as providing no help. While scoring below lectures and labs, 61.4%

of the students rated case studies as providing great, good, or moderate amounts of help in learning course material. Not surprisingly, the textbook readings were not completed by 27.9% of the students and only 34.9% of the students rated this methodology as helping a great, good, or moderate amount.

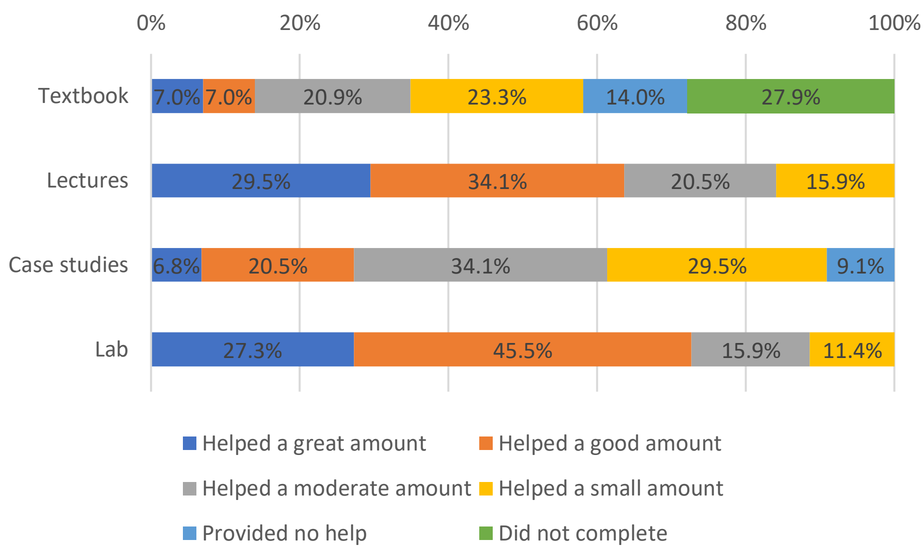

Figure 4.4 *Learning Perceptions of Students Based on Methodology*

The last section of the SALG survey asked students to rate how each of the teaching methodologies utilized in the course helped them to understand the connections between scientific concepts and other aspects of their everyday life. The same Likert scale options were provided for the students, including the "did not complete" option. Figure 4.5 details the percentages of students selecting each category within each teaching methodology.

With relation to their everyday lives, students rated lectures, labs, and case studies more evenly, at least in terms of the number of students identifying these methodologies as providing a great amount of help. When looking at the data more closely, however, 61.4% and 59.1% of the students selected labs and lectures as providing a great or good amount of help while 36.4% of students rated case studies at one of these two higher levels.

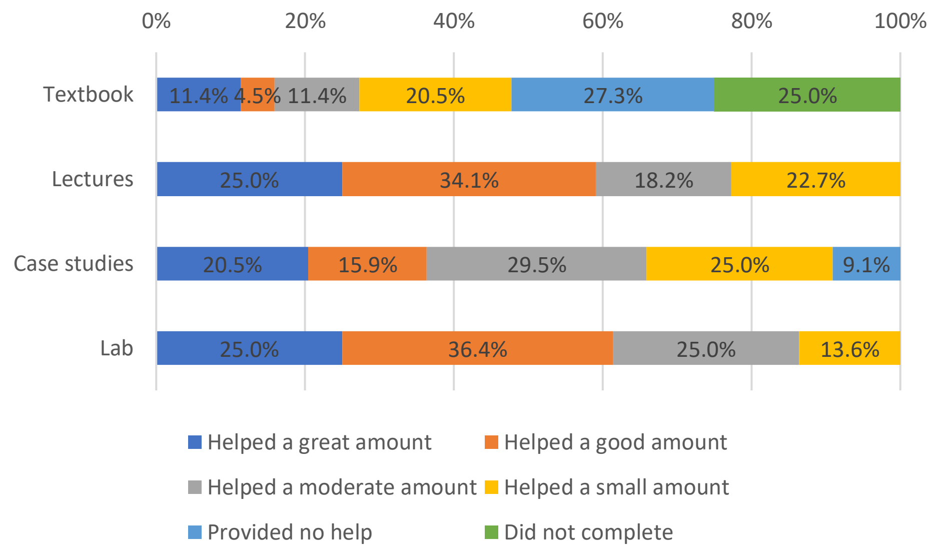

Figure 4.5 *Student Perceptions of Connections Between Science and Everyday Life*

Summary

With 61.4% of students reporting that cases helped a great, good or moderate amount, participants in the class held a generally positive view of case studies helping them learn course material. However, when compared with other teaching methodologies, students appeared to perceive greater learning gains and connections to their everyday life with both lecture and lab. Overall, the textbook seemed to be the least preferred learning methodology with 25% of the students reporting that they did not complete the readings assigned in the course.

Summary of the Data

In this quantitative study, data were collected to assess student growth in critical thinking via two different teaching methodologies: traditional (lecture) instruction and case-based instruction. In order to determine overall gains in critical thinking, the Cornell Critical Thinking Test was utilized at both the beginning and the end of the semester and the scores were compared. The critical thinking ability of students utilizing specific course content was analyzed utilizing scores on selected multiple-choice questions on each of the three unit exams and also by completing End of Chapter (EOC) assignments. The results for both instruments were then analyzed to determine if teaching methodology was a factor in critical thinking gains. Students were also surveyed to see which type of teaching methodology they perceived to assist them the most in learning course material.

Overall, the data collected showed mixed results. There was no significant growth shown in overall critical thinking scores throughout the course of the semester, but moderate gains in critical thinking were observed when utilizing specific course content. In the last chapter, the results of this study will be further interpreted in relationship with similar studies of critical thinking and case-based instruction.

Chapter 5: Implications for Further Research

Throughout the course of this study, the researcher endeavored to solve the problem of increasing critical thinking skills in students in an Anatomy & Physiology classroom without committing large amounts of instructional time to active learning strategies and therefore losing valuable course content. Case studies were identified as a possible solution to this problem as cases can deliver course content while facilitating critical thinking in students (Hartfield, 2010). To investigate the effectiveness of this methodology in increasing critical thinking abilities in students, the following research question was constructed: "How does the implementation of active learning in the form of case studies impact critical thinking in my Anatomy & Physiology classroom?". Additionally, since student perception of learning and actual learning are often different (Deslauriers et al., 2019), the following question was formulated: "How do students perceive case studies to influence learning in my Anatomy & Physiology classroom?

It was hypothesized that students would show more gains in critical thinking when content was delivered utilizing a case-based methodology and that they would perceive to achieve a greater level of learning when taught in this way. While the variable results will be discussed in more detail later in this chapter, there did not seem to be a strong correlation between teaching methodology and improvement in critical thinking. Student perception of learning, on the other hand, did show a strong directional correlation with students perceiving a higher level of learning with lecture and labs than with case-based instruction.

In this chapter, the results of this study will be analyzed and compared with similar research in the field. First, a connection between case-based methodology and student gains in generalized critical thinking skills will be addressed, followed by an analysis of the gains in content-specific critical thinking. Both sections speak to the first research question, with data from the Cornell Critical Thinking Test – Level Z (CCTT-Z) providing insight about general critical thinking skills and the targeted test questions and End of Chapter (EOC) assignments informing content-specific critical thinking. The chapter will then turn its focus towards the second research question, shedding insight on student perceptions of learning based on teaching methodology. Following this section, the chapter will wrap up with broad insights gained and recommendations for future research.

Case Study Methodology and Generalized Critical Thinking Skills

General Critical Thinking Gains

While the need for critical thinking amongst a populace is universally accepted as important (Arum & Roksa, 2011; Davies, 2013; Rayner & Papakonstantinou, 2018), the construct of critical thinking is still debated. Some educational scholars believe that critical thinking is a general skill (Abrami et al., 2015; Davies, 2013) others have found that critical thinking is content-specific and the transferability of critical thinking between disciplines seems to be somewhat limited (Bailin, 2002; Monteiro et al., 2020).

In this study, the pre-test/post-test administration of the Cornell Critical Thinking Test – Level Z was given to assess general critical thinking gains over the course of the semester in which case-based instruction was utilized as one form of teaching methodology. Looking at the initial quantitative analysis, it appears that the critical thinking levels decreased in students over the course of the semester (pre-test = 23.4, post-test=22.6), although the change was not statistically significant. Some of this data may be skewed, however, in terms of the time that students devoted to the taking of the instrument. Of the students whose scores decreased between the two administrations, over 41% spent less than half of the allotted time on the test questions, thus possibly contributing to the low post-test score and overall decrease in average score.

Although the results of the comparison could be disheartening, they are not completely unexpected based on broad-scale data collected by Arum and Roksa (2011), showing that after two years of undergraduate college work critical thinking skills only improved by 0.18 standard deviations and 45% of students had no significant improvement at all. In this Anatomy & Physiology course study, since cases were implemented only sparingly (five over the span of a semester), it may stand to reason that general critical thinking skills stayed relatively constant.

While many studies have measured content-specific critical thinking development in health science courses, only one located study utilized a validated instrument to measure overall, general critical thinking gains. This study showed different results by utilizing the California Critical Thinking Skills Test (CCTST) to measure growth over three years of nurses training utilizing a traditional and case-based approach (Kaddoura, 2011). This author found that the critical thinking scores on the CCTST were significantly improved when students progressed through the case-based instructional program in comparison to the didactic program (Kaddoura, 2011). In relationship to the current study, it may be that the case studies were implemented too infrequently and for too short a time scale to show statistical improvement.

Content-Specific Critical Thinking Learning Gains

The utilization of cases throughout the semester provided an opportunity for students to actively engage with the content in a collective, situated context through which critical thinking skills could be developed. The different cases utilized had differing levels of cognitive challenge – some placing a greater focus on lower-level Bloom's questioning and others asking students to spend more time engaging in critical thinking. In this specific study, the term critical thinking was associated with the top four levels of Bloom's Taxonomy (Apply, Analyze, Evaluate, Create), and two of these levels were required by students throughout the cases in varying amounts (Apply and Analyze). Between 36.8-52.6% of questions in the cases were asked at these critical thinking levels, actively engaging students with the content at a higher cognitive level. The second case study had the lowest percentage of critical thinking questions and the third case study had the largest when totaling both the Apply and Analyze levels while the last two cases had the highest percentage of questions at the Analyze level alone.

While general critical thinking skills showed no improvement over the course of the semester, content-specific critical thinking showed variable results. Content-specific critical thinking skills were assessed in two ways: targeted exam questions and End of Chapter (EOC) assignments. Over the course of the semester, the EOC scores generally improved across all assignments, regardless of teaching methodology. This is hypothesized to be due to students becoming more confident in completing the assignments and generally improving in their skills in answering open-ended questions as more assignments were completed. Since all of the assignments were formatted in a similar manner and feedback was provided as a part of assessment, students were able to more successfully complete the assignments as they gained more practice. Alternatively, the increase in scores could have been due to a slight increase in critical thinking skills, although this did not vary between content delivery type.

Interpretation of the exam data requires a more nuanced approach. While each of the three course exams showed at least a small difference in accuracy when teaching modalities were compared, the difference became more pronounced over time. For the first exam, the significant differences in scores varied between the different Bloom's levels at the apply level in the students that had no chemistry background and in the male subgroup and full class-level in the analyze level with the case study methodology correlating with a higher percentage of questions answered correctly. When taking into account the effect size, it can be noted that the difference in means within the male subgroup is not due to a true difference in learning but instead due to a wide range of scores, resulting in a moderate but not strong effect. With these heterogenous results, it may be safe to say that the variations in scores were not due to actual differences in critical thinking assessment but were instead due to a small sample size, especially within subgroups.

Exam #2 showed a definitive difference between teaching methodologies as significance was found overall and within the analyze level of questioning. Additionally, females and those with no chemistry background showed improvement in exam performance when taught with the case-based method. It is interesting that student answers in the first two exams seemed to show more ability to answer the “Analyze” questions more effectively than the “Apply” questions, as the skill of analyzing is often shown to be at a higher cognitive level than application (Thompson & O’Loughlin, 2015). Kumara et al. (2019) states that application requires utilizing the learned concept within different scenarios while analyzing requires division of the information into smaller parts. When students work on a case study, they are provided with many pieces of information for which they need to determine relevance. For example, in the “Bad Fish” case, students begin the activity by reading a narrative about Dr. Westwood and his ambulance ride and subsequent visit to the emergency department. The students are provided with a long list of symptoms that Dr. Westwood is experiencing, some of which are pertinent to the cause of his visit and others that are extraneous pieces of information that are irrelevant to his situation. To determine the cause of Dr. Westwood’s ailment, the students need to process through this large volume of information to find the pieces that are important for the questions in the case study. It is likely that the practice of breaking down this information into meaningful parts encourages the development of analysis in students more so that the application of knowledge.

The third and last exam of the semester showed different results from the first two – in each of the categories students showed a significant difference in scores based on teaching methodology with students answering the questions covered by cases more accurately than those taught didactically. This is an interesting result as the content contained in the last exam is traditionally the most difficult for students. One explanation for this difference would be the cases themselves and the familiarity that students had gained with utilizing case studies by the end of the semester. At the beginning of the semester, most students were not familiar with the case study methodology as evidenced by casual conversations with students. It has been noted that cases may be frustrating for students, especially if they have a lower maturity level or are accustomed to a traditional teaching methodology (Cliff & Wright, 1996; Rhodes et al., 2020). As students became more familiar with cases and levels of questioning encountered within, they became more adept at utilizing them as a learning tool, thus their cognitive gains from using case studies improved as the semester progressed. Cliff & Wright (1996) allude to this when mentioning that cases need to be used on a regular basis to help them get accustomed to learning from them. This sentiment is also reflected by Michael (2006), "if you expect students to use knowledge to solve any kind of problem, you must provide them with opportunities to practice the needed skills" to do so (p. 161). With more practice answering questions requiring critical thinking, students were able to complete the activity with a higher level of competence.

The timing of the presentation of the cases may also have contributed to the increase in scores throughout the course. In the current approach, cases were utilized as a replacement for lecture on material to preserve the volume of course content. While every effort was made to ensure that this was the case, it was evident by the end of the semester that students were struggling with teasing out complex pieces of physiological information from the case without having had exposure to the content beforehand. As the semester progressed, I started to cover some of the material didactically before students would encounter the information in the cases. This allowed the case study sessions to flow more easily and provided a suitable amount of challenge for the students. Ramaekers et al., (2011) noted that the cognitive load of a case is often reduced when students are exposed to the material before completing a case. If this was the case in the later part of the semester, it may have been that the cognitive load was decreased for students, allowing them to more fully process the material presented in the case study. In the current study, the presentation of material before the completion of the corresponding case may have caused the increase in scores at the end of the semester as the mini-lecture provided students with additional exposure to the material which may have allowed deeper processing and long-term retention of the material.

The variable results in this study are echoed by other authors as well. While some have found statistically significant increases in content-based performance when utilizing case-based instruction versus other methodologies (Bansal & Goyal, 2017; Bennal et al., 2016; Bonney, 2015; Cliff & Wright, 2016; Kulak & Newton, 2015; Nasr, 2012; Pekary et al., 2021), these studies were comparing different variables utilizing a quasi-experimental set-up and a relatively small sample size. While several different research designs were implemented in these studies, two of those studies (Bonney, 2015; Pekary et al., 2021) closely mirrored the current study. The study conducted by Pekary et al. (2021) involved two different sections of Anatomy & Physiology, one taught using traditional lecturing only and the other taught with case studies in addition to didactic instruction. It is interesting to note that in the case study class section, cases were utilized after students have been exposed to the topic before they completed the case study and there was a significant difference in the second two exams compared with the control group (Pekary et al., 2021). In both the current study and the Pekary et al. (2021) study, exam performance seemed to improve over the course of the semester.

While the results of the current study partially mirror the results obtained by Pekary et al. (2021), the results differ to a greater degree than those recorded by Bonney (2012). In the Bonney (2012) study, four cases were implemented throughout the course of the semester and exam question performance was compared to teaching methodology to determine if case-based instruction resulted in increased performance. Overall, students performed significantly better on the questions that were taught via case-based instruction compared with other methods of instruction including class discussion and textbook readings (Bonney, 2012). The results of this study were a bit ambiguous as it was difficult to determine what topics were taught utilizing non-case methods. It could be that the content chosen for case-study coverage was easier in difficulty, thus resulting in higher overall performance on exam questions covering that material.

Other authors (King-Heiden & Lister, 2019; Rhodes et al., 2020; Yadav, Shaver, & Meckl, 2010) have not found a statistical difference between exams scores where content was taught via case-studies as students performed equally despite methodology. Thistlethwaite et al. (2012) performed a meta-analysis on 104 research articles comparing case-based instruction to other teaching methodologies and, while some studies found increases in student performance, the majority found no statistical difference. Thus, Thistlethwaite et al. (2012) determined that the results were inconclusive. This seems to echo the findings of the current study as well. While gains were seen in some areas, this significance may be due to other variables other than instructional methodology alone.

Student Perception of Learning

Student responses to the Student Assessment of Learning Gains (SALG) survey provided insight to the student's individual perception of learning when case studies were used as an instructional tool. When evaluated independently, the cases showed a majority of students (70.8%) rating the cases as providing a great, good, or moderate amount of help in understanding the material. This seems to reflect the ideas in the literature when cases are evaluated independently of other methodologies. When assessed alone, a majority of students perceive that they assist in the learning of the material (Bansal & Goyal, 2017; Bennal et al., 2016, Cliff & Wright, 1996, Nasr, 2012; Thistlethwaite et al., 2012; Yadav et al., 2010). Most of the previous studies examining student perception of learning utilizing case studies relies on quantitative data that merely correlates the implementation of cases with a higher perception of learning. However, Bansal et al. (2017) identified several possible reasons for this perception including student identification of real-life relevance and the fact that the cases kept student engaged during the session. Further research is required to determine what specific aspects of case methodology contributes to student perception of learning using this particular strategy.

Additionally, in the current study, there was a moderate amount of variability between individual case studies and student perception of learning. This may be due to the case selected – some have more appeal and connection to students than others – or it may be due to the topics covered in each of the cases. The first case completed in the fall semester was titled “The Biochemistry of Curly and Straight Hair” and this specific case had a larger percentage of students (41.8%) cited this case as providing either no help or just a small amount of help in learning course material. While this higher percentage may be due to its placement at the beginning of the year causing students to misremember its helpfulness, the content contained in the case may also been less engaging for students. This was the only case study utilized that did not present the information in terms of a problem or disease to solve as the case focused on the chemical and structural differences between curly and straight hair. To be more effective, the content covered in this case should be reworked to be more relevant for students, thus increasing the “situated” intent of the activity. In terms of situated cognition, the real-life nature of the case needs to be more engaging and relevant for students if they are to situate themselves within the context of the case, thus providing a more authentic environment for learning to occur.

The last case study that was completed in the fall of 2022 was titled “Bad Fish: Human Anatomy & Physiology Edition” and was focused on the physiology of the nervous system. A smaller percentage of students (46.5%) noted that this case helped a great or good amount compared with the two cases completed prior (50% and 53.5%). This is an interesting trend considering that this was the last case completed throughout the semester and students would have a higher level of familiarity with cases at this point of the semester. While this lower preference may be due to student fatigue in the course, it also may be correlated with the overall structure of this specific case. In most case studies utilized throughout the study, a brief passage was followed by a short set of between 2-7 questions. In the nervous system physiology case, the beginning narrative was following by 16 short answer questions that may have seemed overwhelming to the students especially at the late point in the semester. The effectiveness of different case structures and their effectiveness is also an area for future research.

When compared with other teaching methodologies, cases were not perceived to be of the most help when learning content. In the current study, 88.7% and 84.1% rated labs and lectures (respectively) as providing a great, good, or moderate amount of help in learning course content while 61.4% rated cases in the same manner. Only 34.9% of students rated the textbook as being great, good, or moderate in helping master content. These results are in line with another study by Pekary et al. (2021) as students in this study rated listening to lectures above cases in terms of help provided to students' learning. The current study is a bit unique in this way as most other studies only assess cases independently and not in comparison with other teaching methodologies. However, it is not surprising that students rate labs as most effective as authors have noted that students most often indicate a preference for learning kinesthetically (Johnston et al., 2015). Additionally, students often rate passive forms of instruction (lecture) as more effective in learning material when compared with active learning strategies, even though more learning is measured when active strategies are employed (Deslauriers et al., 2019). This has led Deslaueriers et al. (2019) to conclude that students' perceptions of learning are poor indicators of true learning.

It is also of note to consider the impacts of the COVID-19 pandemic on learning preferences and effectiveness. In a study completed by Hughes et al. (2022), students in anatomy & physiology classrooms were surveyed about their learning preferences both before and after the pandemic. Compared to pre-pandemic levels, students were less likely to prefer small group work with 43.9% of students preferring small group discussion before COVID-19 and 28.0% after the pandemic (Hughes et al., 2022). This resistance to working in small groups was noted by the author throughout the course of this study and also in the course evaluations at the end of the semester. During the work on case studies, students were very hesitant to talk to each other and preferred to work alone. This was reflected in many of the narrative comments in the course evaluation with one student stating, "I didn't enjoy the case studies very much, maybe something similar we can do in class by ourselves". According to social constructivism, removing this collective sense-making component could have led to lower levels of learning throughout the activities (Shepardson & Britsch, 2015).

Limitations of the Current Study

The current study, while significant to the author, does have some important limitations. The first major limitation of the study is its quasi-experimental nature since there was no randomization of the students that participated in the study. The study participants were limited to the 50 students that signed up for the course in the fall of 2022 and could not be compared to prior sections since data were not available for prior sections. Ideally, the study would consist of two different sections of the course, one experimental and one control, taught in the same semester, with random student selection. Because of the nature of the author's university, this was not possible.

A second limitation was the low number of participants. While 50 students is a large class at the author's university, this sample size is not large enough to draw sweeping conclusions about the effectiveness about the different teaching methodologies employed. Therefore, the gains in critical thinking shown on the multiple-choice exam question scores, while important, are too small to make large generalizations about student learning. Additionally, the low sample size did not allow for more detailed connected to be made between subgroups. For example, it would have been interesting to analyze the data to determine if level of chemistry preparedness impacted genders differently, however, with such low numbers of individuals in each group, these conclusions cannot be accurately drawn.

A third limitation was the structure of the assignments and exam questions utilized in the study. While every effort was made to produce questions and assignments of equal difficulty throughout the course, there was no way to standardize this question selection. Therefore, differences in scores on the End of Chapter (EOC) assignments and exam questions may have been partially due to differences in difficulty and not necessarily critical thinking.

Last, the amount of instructional time devoted to specific topics varied throughout the semester. At the beginning of the semester, the case studies were utilized in the classroom to exclusively deliver content and the material in the case studies was not covered didactically during lecture instruction. As the semester progressed, the topics became more complex and the amount of material covered in the cases was a bit broader, even though a similar number of objectives were covered in each case. Because of this, some of the content was covered both in lecture and the case studies. While the amount of lecture time was relatively short (10-20 minutes), this overlap in content coverage may have impacted student performance on exams.

Summary and Recommendations for Further Research

Critical thinking development and enhancement is one of the most frequently listed objectives for higher education (Grant & Smith, 2018). Unfortunately, the large volume of content covered, especially in Anatomy & Physiology courses, can often conflict with this objective (Pekary et al., 2021). Additionally, while critical thinking is known to be best developed in an active setting (Birk et al., 2019), students often perceive this type of classroom environment as less effective in fostering learning (Pekary et al., 2021).

The current study attempted to utilize case-based instruction as a possible solution to this quandary, actively involving students in meaning-making through biologically and medically relevant cases to teach and reinforce content. While there was some evidence that growth in critical thinking skills occurred over the course of the semester, the results were generally inconclusive. Additionally, students found them to be less helpful in learning content than lectures and laboratory activities. Based on the results of this study, are case studies helpful in increasing critical thinking in students in anatomy & physiology? The author believes that the answer is yes as portions of the data collected in this study supports this conclusion. However, several suggestions are made for further studies and research in this area.

First, it would be valuable to implement case study methodology over a full year of anatomy & physiology instruction. While the results of the first exam showed little difference between the control and experimental questions, the results on the third and final exam showed a significant difference between the two methodologies, which is similar to results obtained in the Pekary et al. (2021) study. A longer study spanning two semesters would help to determine if this trend continued. This would provide students with less experience learning in active environments time to become accustomed to case study methodology since these are the students that usually struggle the most when they are not familiar with this type of educational environment (Cliff & Wright, 1996; Rhodes et al., 2020).

Second, decreasing the cognitive load by reformatting the structure and presentation of the cases may improve learning outcomes. In the current study, cases were utilized to teach difficult, complex physiological mechanisms such as nervous impulse generation and muscle contraction. While each case study covered a similar amount of material (2-3 HAPS objectives), each of these objectives deal heavily with physiological concepts which are characteristically more difficult for students to grasp than concepts in anatomy (Slominski et al., 2019). It may be beneficial to utilize cases after an initial exposure to the content has been made (Pekary et al., 2021), thus slightly reducing the cognitive load of the cases (Ramaekers et al., 2011). While it was the intent of the author that students would read a selected textbook passage before the case was completed, this task was reported to be omitted by 27.8% of the students in the course. In the future, it may be beneficial to have short lectures that students are required to view before coming to class on the day of the case study activity. Having an initial exposure to more difficult course content before the completion of a case study may be helpful in lowering the cognitive load required for students thus resulting in greater learning gains.

Additionally, Cliff and Wright (1996) posit that the most effective cases are short, giving all relevant information without extraneous detail, and not too complex or involved. It would be of value to restructure the content and timing of delivery of the cases to determine if critical thinking was more greatly impacted.

Third, it may be helpful to integrate the cases more fully into a specific unit or course which would increase the students' engagement with the case and consequently lead to increased embodiment. One way that this could be done is by utilizing a process known as a storyline. A storyline unit begins with an anchoring phenomenon routine that helps to assist students in moving through a process of identifying an event of interest, asking questions about that situation, and then exploring the phenomenon and attempting to make sense of the event (Reiser et al., 2021). The initial patient story presented in a case study could serve as this opening event or situation that students are presented with when starting a new content unit. The class could then develop their own questions concerning the scenario and be supported in working through the phenomena that are involved. While some content in the unit would be covered didactically, the class could be frequently reminded of the case, thus building interest and scaffolding content throughout the unit as opposed to the entire case being completed in one or two days of class.

One way that these cases could be more fully integrated into the chapter content is by utilizing an integrated STEM methodology. An integrated STEM approach seeks to incorporate all areas of STEM education (science, technology, engineering, and math) into instruction (Roehrig et al., 2021). At the K-12 level, research has found that student engagement increases when curriculum is presented in a more integrated fashion (Guzey & Li, 2022). Intentionally incorporating other STEM disciplines into each unit, along with the cases as an anchor, could potentially increase buy-in at the undergraduate level as well. This more complete integration of the cases into the course could then increase both engagement via personal investment and subsequently embodiment by the students (Reiser et al., 2021).

Last, it would be helpful to understand if group make-up impacts the effectiveness of group dynamics, thus influencing the learning gains when utilizing this teaching methodology. Groups in this study were randomly chosen by the instructor, but influenced by the amount of prior chemistry exposure, as at least one student in each group had completed an entire year of General Inorganic Chemistry. While this structure was chosen because of prior research indicating its effectiveness (Donovan et al., 2018; Kanika et al., 2022), it would be valuable to determine if this type of structuring is still effective in the post-pandemic world or if it would be of greater value to the students if they would choose their own group.

The goal of increasing critical thinking competence needs to remain a high priority for undergraduate instructors, including those in anatomy and physiology classrooms. Especially in this ever-changing world, the need to solve problems, analyze data, and apply concepts is paramount for success in both personal and professional life. Case studies may be an avenue that instructors choose to utilize to meet that end, but care needs to be taken that this methodology is implemented in a thoughtful and intentional way in order for that goal to become a reality.

References

Abercrombie, S., Hushman, C.J., & Carbonneau, K.J. (2019). The influence of timing of peer cooperation on learning. *Educational Psychology, 39*(7), 881-899. https://doi.org/10.1080/014434110.2019.1567690

Abrami, P.C., Bernard, R.M., Borokhovski, E., Waddington, D.I., Wade, C.A., & Persson, T. (2015). Strategies for teaching students to thinking critically: A meta-analysis. *Review of Educational Research, 85*(2), 275-414.

Adams, N.E. (2015). Bloom's taxonomy of cognitive learning objectives. *Journal of the Medical Library Association, 103*(3), 152-153.

Akiha, K., Brigham, E., Couch, B.A., Lewin, J., Stains, M., Stetzer, M.R., Vinson, E.L. & Smith, M.K. (2018). What types of instructional shifts do students experience? Investigating active learning in science, technology, engineering, and math classes across key transition points from middle school to the university level. *Frontiers in Education, 2:*68. doi: 10.3389/feduc.2017.00068.

Ali, S.H., & Ruit, K.G. (2015). The impact of item flaws, testing at low cognitive level, and low distractor functioning on multiple-choice question quality. *Perspectives in Medical Education, 4,* 24-251.

Allchin, D. (2013). Problem- and case-based learning in science: An introduction to distinctions, values, and outcomes. *CBE – Life Sciences Education, 12*, 364-372.

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education: A call to action.* https://visionandchange.org/wp-content/uploads/2013/11/aaas-VISchange-web1113.pdf

American Association of Colleges of Nursing. (2022). *The essentials: Core competencies for professional nursing education.* https://www.aacnnursing.org/Essentials

Anderson, L. W. and Krathwohl, D. R. (Eds.). (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Allyn & Bacon.

Anmin, A.M., Corebima, A.D., Zubaidah, S., & Muhanal, S. (2019). The correlation between metacognitive skills and critical thinking skills at the implementation of four different learning strategies in animal physiology lectures. *European Journal of Educational Research, 9*(1), 143-163. doi: 10.12973/eu.jer.9.1.143.

Anthony, G. (2017). Active learning in a constructivist framework. *Educational Studies In Mathematics, 31*(4), 349-369.

Armstrong, P. (2010). *Boom's taxonomy.* Vanderbilt University Center for Teaching. Retrieved 7/19/21 from https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/.

Artino Jr., A.R. (2013). It's not all in your head: Viewing graduate medical education through the lens of situated cognition. *Journal of Graduate Medical Education, 5*(2), 177-179. http://dx.doi.org/10.4300/JGME-D-13-00059.1.

Arum, R. & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses*. The University of Chicago Press.

Bächtold, M. (2013). What do students "construct" according to constructivism in science education? *Research In Science Education, 23*, 2477-2496. doi:10.1007/s11165-013-9369-7.

Baeten, M., Dochy, F. & Struyven, K. (2013). The effects of different learning environments on students' motivation for learning and their achievement. *British Journal of Educational Psychology, 83,* 484-501. https://doi.org/10.1111/j.2044-8279.2012.02076.x

Bailin, S. (2002). Critical thinking and science education. *Science & Education, 11,* 361-375.

Bansal, M. & Goyal, M. (2017). To introduce and measure the effectiveness of case based learning in physiology. *International Journal of Research in Medical Sciences, 5*(2), 437-445.

Bennal, A.S., Pattar, M.Y., & Taklikar, R.H. (2016). Effectiveness of "case-based learning" in physiology. *National Journal of Physiology, Pharmacy and Pharmacology, 6*(1), 65-67.

Bibler-Zaidi, N.L., Grob, K.L., Monrad, S.M., Kurtz, J.B., Tai, A., Ahmed, A.Z., Gruppen, L.D., & Santen, S.A. (2018). Pushing critical thinking skills with multiple-choice questions: Does Bloom's Taxonomy work? *Academic Medicine, 93*(6), 856-859.

Birk, T., Lee, V., & Corbit, A. (2019). The effects of sex, ethnicity, and socioeconomic status on student perceptions of case-based learning in anatomy & physiology classes. *HAPS Educator, 23*(2), 385-395. doi:10.21692/haps.2019.022.

Bissell, A.N. & Lemons, P.P. (2006). A new method for assessing critical thinking in the classroom. *BioScience, 56*(1), 66-72.

Bluffton University. (n.d.) *Bluffton at a glance*. https://www.bluffton.edu/about/bluffton-at-a-glance/index.aspx.

Bonney, K.M. (2015). Case study teaching method improves student performance and perceptions of learning gains. *Journal of Microbiology & Biology Education, 16*(1), 21-28.

Bonwell, C.C. & Eison, J.A. (1991). *Active learning: Creating excitement in the classroom. ASHE-ERIC Higher Education Report 1.* Washington D.C.: The George Washington University School of Education and Human Development.

Boston University (n.d.). *Case-based learning.* Center for Teaching & Learning. https://www.bu.edu/ctl/guides/case-based-learning/

Burgess, A., Matar, E., Roberts, C., Haq, I., Wynter, L., Singer, J., Kalman, E., & Bleasel, J. (2021). Scaffolding medical student knowledge and skills: Team-based learning (TBL) and case-based learning (CBL). *BMC Medical Education, 21,* 238. https://doi.org/10.1186/s12909-021-02638-3

Camill, P. (2006). Case studies add value to a diverse teaching portfolio is science courses. *Journal of College Science Teaching, 36*(2), 31-37.

Choudhury, B. & Freemont, A. (2017). Assessment of anatomical knowledge: Approaches taken by higher education institutions. *Clinical Anatomy, 30*(3), 290-299.

Chen, X. (2013). *STEM attrition: College students' paths into and out of STEM fields* (NCES 2014-001). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Cliff, W.H. & Wright, A.W. (1996). Directed case study method for teaching human anatomy & physiology. *Advances in Physiology Education, 15*(1), S19-S28.

Cohen J. (1988). *Statistical power analysis for the behavioral sciences.* Routledge Academic.

Colburn, A. (2000). Constructivism: Science education's "grand unifying theory". *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 74*(1), 9-12, doi: 10.1080/00098655.2000.11478630

College Factual. (n.d.). *Bluffton Diversity and Demographics*.

Creswell, J.W. & Creswell, J.D. (2018). *Research Design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publishing.

Davies, M. (2013). Critical thinking and the disciplines reconsidered. *Higher Education Research & Development, 32*(4), 529-544. doi: 10.1080/07294360.2012.697878.

Deslauriers, L., McCarty, L.S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *PNAS, 116*(39), 19251-19257.

Donaldson, T., Fore, G.A., Filippelli, G.M., & Hess, J.L. (2020). A systematic review of the literature on situated learning in the geosciences: Beyond the classroom. *International Journal of Science Education, 42*(5), 722-743. doi: 10.1080/09500693.2020/1727060.

Donovan, D.A., Connell, G.L., & Grunspan, D.Z. (2018). Student learning outcomes and attitudes using three methods of group formation in a nonmajors biology class. *CBE – Life Sciences Education, 17*(4), 1-14. https://doi.org/10.1187/cbe.17-12-0283

Dwyer, C.P., Hogan, M.J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity, 12,* 43-52. http://dx.doi.org/10.1016/j.tsc.2013.12.004

Dyer, J.O. & Elsenpeter, R.L. (2018). Utilizing quantitative analyses of active learning assignments to assess learning and retention in a general biology course. *Bioscene: Journal of College Biology Teaching, 44*(1), 3-12.

Efron, S.E. & Ravid, R. (2020). *Action research in education* (2nd ed.). The Guilford Press.

Ennis, R.H., Millman, J. & Tomko, T.N. (2005). Cornell critical thinking tests level X and level Z manual, 5th ed., *The Critical Thinking Co*.

Facione, P. (1990). *The Delphi Report: Executive summary; Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction.* California: The California Academic Press.

Faust, J.L. & Paulson, D. (1998). Active learning in the college classroom. *Excellence in College Teaching, 9*(2), 3-24.

Fraihat, M.A.K., Khasawneh, A.A., & Al-Barakat, A.A. (2022). The effect of situated learning environment in enhancing mathematical reasoning and proof among tenth grade students. *EURASIA Journal of Mathematics, Science, and Technology Education, 18*(6), em2120. https://doi.org/10.29333/ejmste/12088.

Freeman, S. Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., & Wenderoth, M.P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS, 11*(23). doi: 10.1073/pnas.1319030111.

French, B.F., Hand, B., Therrien, W.J., & Vazquez, J.A.V. (2012). Detection of sex differential item functioning in the Cornell Critical Thinking Test. *European Journal of Psychologic al Assessment, 28*(3), 201-207.

Grant, M. & Smith, M. (2018). Quantifying assessment of undergraduate critical thinking. *Journal of College Teaching & Learning, 15*(1), 27-38. doi: 10.19030/tlc.v15i1.10199.

Guzey, S.S. & Li, W. (2022). Engagement and science achievement in the context of integrated STEM education: A longitudinal study. *Journal of Science Education and Technology, 32,* 168-180.

Harman, T, Bertrand, B., Greer, A., Pettus, A., Jennings, J., Wall-Bassett, E., & Babatunde, O.T. (2015). Case-based learning facilitates critical thinking in undergraduate nutrition education: Students describe the big picture. *Journal of the Academy of Nutrition and Dietetics, 115*(3), 378-388. http://dx.doi.org/10.1016/j.jand.2014.09.003.

Hartfield, P.J. (2010). Reinforcing constructivist teaching in advanced level biochemistry through the introduction of case-based learning activities. *Journal of Learning Design, 3*(3). 20-31. http://doi.org/10.5204/jld.v3i3.59.

Hays, R. (2008). A practical guide to curriculum design: problem-based, case-based or traditional. *The Clinical Teacher, 5,* 73-77.

Heath, A. & Weege, M.R. (2017). Improving critical thinking through case-based lectures. *Radiation Therapist, 26*(2), 206-208.

Herr, K. & Anderson, G.L. (2015). *The action research dissertation* (2nd ed.). Sage Publications, Inc.

Herreid, C.F. (2004). Can case studies be used to teach critical thinking? *Journal of College Science Teaching, 33*(6), 12-14.

Herreid, C.F., Schiller, N.A., Herreid, K.F. (2012*). Science Stories: Using case studies to teach critical thinking.* NSTA Press.

Hobbins, J.O., Murrant, C.L., Snook. L.A., Tishinsky, J.M., & Ritchie, K.L. (2020). Incorporating higher order thinking and deep learning in a large, lecture-based human physiology course: Can we do it? *Advances in Physiology Education, 44*, 670-678.

Hoffer, E.R. (2020). Case-based teaching: Using stories for engagement and inclusion. *International Journal on Social and Education Sciences, 2*(2), 75-79.

Holmes, A. G. D. (2020). Researcher positionality – A consideration of its influence and place in qualitative research – A new researcher guide. *Shanlax International Journal of Education, 8*(4). 1-10. doi: 10.34293/education.v8i4.3232.

Holmes, N.G., Wieman, C.E., & Bonn, D.A. (2015). Teaching critical thinking. *PNAS, 112, 36,* 11199-11204.

Hopper, M.K. (2018). Alphabet soup of active learning: Comparison of PBL, CBL, and TBL. *HAPS Educator, 22*(2), 144-149. doi: 10.21692/haps.2018.019.

Hughes, F.P. & Keller, K.L. (2022). A comparison of student preferences for presentation forms in an undergraduate human anatomy & physiology course before and after the pandemic. *HAPS Educator, 26*(3), 12-20.

Human Anatomy & Physiology Society (2019). *Anatomy and physiology learning outcomes.* https://www.hapsweb.org/page/Learning_Outcomes .

Human Anatomy & Physiology Society (2019). *Course guidelines for undergraduate instruction of anatomy and physiology.* https://www.hapsweb.org/page/course_guidelines

Human Anatomy & Physiology Society (2020). *HAPS learning goals for students*. https://www.hapsweb.org/general/custom.asp?page=learning_goals .

Jensen, J.L., Kummer, T.A., & Godoy, P.D. (2014). Improvements from a flipped classroom may simply be the fruits of active learning. *CBE – Life Sciences Education, 14*(4). doi: 10.1187/10.1187/cbe.14-08-0129

Johnston, A.N.B., Hamill, J., Barton, M.J., Baldwin, S., Percival., J., Williams-Pritchard, G., Salvage-Jones, J., & Todorovic, M. (2015). Student learning styles in anatomy and physiology courses: Meeting the needs of nursing students. *Nurse Education in Practice, 15*, 415-420.

Kaddoura, M.A. (2011). Critical thinking skills of nursing students in lecture-based teaching and case-based learning. *International Journal for the Scholarship of Teaching and Learning, 5*(2), 20. doi: 10.20429/ijsotl.2011.050220.

Kanika, S.C., Chakraborty, P., & Madan, M. (2022). Effect of different grouping arrangements on students' achievement and experience in collaborative learning environment. *Interactive Learning Environments,* doi: 10.1080/10494820.2022.2036764*.*

Kim, MK, Patel, R.A., Uchizono, J.A. & Beck, L. (2012). Incorporation of Bloom's taxonomy into multiple-choice examination questions for a pharmacotherapeutics course. *American Journal of Pharmaceutical Education, 76*(6).

King-Heiden, T.C. & Lister. M. (2019). Using case-study based modules to promote a better understanding of evolution in an undergraduate anatomy and physiology course, *Journal of Biological Education, 53*(5), 477-491,

Kruckeberg, R.K. (2006). A Deweyan perspective on science education: Constructivism, experience, and why we learn science. *Science & Education, 15*, 1-30. doi:10.1007/s11191-004-4812-9.

Kulak, V. & Newton, G. (2014). A guide to using case-based learning in biochemistry education. *Biochemistry and Molecular Biology Education, 42*(6), 457-473. http://doi.wiley.com/10.1002/bmb.20823

Kulak, V. & Newton, G. (2015). An investigation of the pedagogical impact of using case-based learning in a undergraduate biochemistry course. *International Journal of Higher Education, 4*(4), 13-24.

Kumara, B.T.G.S., Brahmana, A., & Paik, I. (2019). Bloom's taxonomy and rules-based question analysis approach for measuring the quality of examination papers. *International Journal of Knowledge Engineering, 5*(1), 20-24.

Labov, J.B., Reid, A.H., & Yamamoto, K.R. (2010). Integrated biology and undergraduate science education: A new biology education for the twenty-first century? *CBE – Life Sciences Education, 9,* 10-16. doi: 10.1187/cbe.09-12-0092.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Frontiers in Psychology, 4*, 1-12. doi: 10.3389/fpsyg.2013/00863.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lax, N., Morris, J., & Kolber, B.J. (2017). A partial flip classroom exercise in a large introductory general biology course increases performance at multiple levels. *Journal of Biological Education, 51*(4), 412-426. doi: 10.1080/00219226.2016.1257503

Lent, D.D., Estes. K.M., & Hansen, A.K. (2021). Increasing faculty involvement in the undergraduate interdisciplinary learning experience. *Integrative & Comparative Biology, 61*(3), 1002-1012. https://doi.org/10.1093/icb/icab109.

Loyalka, P., Liu, O.L., Li, G., Kardanova, E., Chirikov, I., Hu, S., Yu, N., Ma, L., Guo, F., Beteille, T., Tognatta, N., Gu, L., Ling, G., Federiakin, D., Wang, H., Khanna, S., Bhuradia, A., Shi, Z., & Li, Y. (2021). Skill levels and gains in university STEM education in China, India, Russia and the United States. *Nature Human Behavior, 6*, 892-904.

Mason, L.E., Krutka, D., & Stoddard, J. (2018). Media literacy, democracy, and the challenge of fake news. *Journal of Media Literacy Education, 10*(2), 1-10. https://doi.org/10.23860/JMLE-2018-10-2-1.

McLean, S., Attardi, S.M., Faden, L., & Goldszmidt, M. (2016). Flipped classrooms and student learning; Not just surface gains. *Advances in Physiology Education, 40*(1), 47-55. doi: 10.1152/advan.00098.2015.

McMurray, M.A., and others. (1989). Identifying domain-specific aspects of critical thinking ability in solving problems in biology. *Annual Meeting of the Southwest Educational Research Association*.

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education, 30,* 159-167. http://doi.org/10.1152/advan.00053.2006

Monteiro, S., Sherbino, J., Sibbald, M., & Norman, G. (2020). Critical thinking, biases and dual processing: The enduring myth of generalizable skills. *Medical Education, 54*(1), 66-73.

Murray-Nseula, M. (2011). Incorporating case studies into an undergraduate genetics course. *Journal of the Scholarship of Teaching and Learning, 11*(3), 75-85.

Nasr, P. (2012). A report on case study application in an undergraduate anatomy & physiology course. *AURCO Journal*, *17,* 123-139.

National Science Board. (2020). *Science & engineering indicators: The state of U.S. science and engineering 2020*. Alexandria, VA: National Science Board and National Science Foundation. https://ncses.nsf.gov/pubs/nsb20201

National Science Teaching Association (n.d.). *NCCSTS Case Collection.* https://www.nsta.org/case-studies

O'Neill, G. & Mcmahon, T. (2005). Student-centered learning: What does it mean for students and lecturers? In G. O'Neill, S. Moore, & B. McMullin (Eds.) *Emerging Issues in the Practice of University Learning and Teaching* (pp. 30-39). All Ireland Society for Higher Education.

Palmer, E.J. & Devitt, P.G. (2007). Assessment of higher order cognitive skills in undergraduate education: Modified essay or multiple-choice questions? Research paper. *BMC Medical Education, 7*(49).

Pekary, M.M., Jellyman, J.K., Giang, M.T., & Beardsley, P.M. (2021). Examining the impact of case studies on student learning, interest, motivation, and belonging in undergraduate human physiology. *HAPS Educator, 25*(2), 30-43.

Poirier, T.I. (2017). Is lecturing obsolete? Advocating for high value transformative lecturing. *American Journal of Pharmaceutical Education, 81*(5), 83. doi: 10.5688.ajpe81583.

Prince, M.J. & Felder, R.M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123-138.

Ramaekers, S., van Keulen, H., Kremer, W., Pilot, A., & van Beukelen. (2011). Effective teaching in case-based education: Patterns in teacher behavior and their impact on the students' clinical problem solving and learning. *International Journal of Teaching and Learning in Higher Education, 23*(3), 303-313.

Rayner, G.M. & Papakonstantinou, T. (2018). Foundation biology students' critical thinking ability: Self-efficacy versus actuality. *Journal of University Teaching & Learning Practice, 15*(5).

Reiser, B.J., Novak, M., McGill, T.A.W., & Penuel, W.R. (2021). Storyline units: An instructional model to support coherence from the students' perspective. *Journal of Science Teacher Education, 32*(7), 805-829.

Reynders, G., Lantz, J., Ruder, S.M., Stanford, C.L., & Cole, R.S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. *International Journal of STEM Education, 7*(1), 1-15. https://doi.org/10.1186/s40594-020-00208-5.

Rhodes, A., Wilson, A., & Rozell, T. (2020). Value of case-based learning within STEM courses: Is it the method or is it the student? *CBE – Life Sciences Education, 19*(3). doi:10.1187/cbe.19-10-0200.

Rohrig, G.H., Dare, E.A., Ring-Whalen, E., & Wieselmann, J.R. (2021). Understanding coherence and integration in integrated STEM curriculum. *International Journal of STEM Education, 8*(2). doi: https://doi.org/10.1186/s40594-020-00259-8.

Romeo, E.M. (2013). The predictive ability of critical thinking, nursing GPA, and SAT scores on first-time NCLEX-RN performance. *Nursing Education Perspectives, 34*(4), 248-253.

Rosenberg, Hilton, M. L., & Dibner, K. A. (2018). *Indicators for monitoring undergraduate STEM education* (Rosenberg, M. L. Hilton, & K. A. Dibner, Eds.). The National Academies Press.

Ross, D., Loeffler, K., Schipper, S., Vandermeer, B., & Allan, G.M. (2013). Do scores on three commonly used measures of critical thinking correlate with academic success of health professions trainees? A systematic review and meta-analysis. *Academic Medicine, 88*(5), 724-734. doi: 10.1097IACM.0b013e31828b0823.

Santos, L.F. (2017). The role of critical thinking in science education. *Journal of Education and Practice, 8*(20), 159-173.

Savery, J.R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1). https://doi.org/10.7771/1541-5015.1002

Schunk, D. (2020). *Learning theories: An educational perspective* (8th ed.). Pearson.

Seibert, S.A. (2021). Problem-based learning: A strategy to foster generation Z's critical thinking and perseverance. *Teaching and Learning in Nursing, 61*(1), 85-88.

Shepardson, D.P. & Britsch, S. (2015). Mediating meaning in the social world of the science classroom. *Electronic Journal of Science Education, 19*(4), 1-13.

Slattery, P. (2013). *Curriculum development in the postmodern era: Teaching and learning in an age of accountability* (3rd ed.). Routledge.

Slominski, T., Grindberg, S., & Momsen, J. (2019). Physiology is hard: A replication study of students' perceived learning difficulties. *Advances in Physiology Education, 43,* 121-127. doi:10.1152/advan.00040.2018.

Stains, M., Harshman, J., Barker, M.K., Chasteen, S.V., Cole, R., DeChenne-Peters, S.E., Eagan Jr., M.K., Esson, J.M., Knight, J.K., Laski, F.A., Levis-Fitzgerald, M. Lee, C.J., Lo, S.M., McDonnell, L.M., McKay, T.A., Michelotti, N., Palmer, M.S., Plank, K.M., Rodela, T.M. … Young, A.M. (2018). Anatomy of STEM teaching in American universities: A snapshot from a large-scale observation study. *Science*, *359*(6383), 1468-1470. doi:10.1126/science.aap8892.

Styers, M.L., VanZandt, P.A., Hayden, K.L. (2018). Active learning in flipped life science courses promotes development of critical thinking skills. *CBE – Life Sciences Education, 17*(3). doi: 10.1187/cbe.16-11-0332.

Theobald, E.J., Hill, M.J., Tran, E., Agarwal, S., Arroyo, E.N., Behling, S., Chambwe, N., Cintron, D.L., Cooper, J.D., Dunster, G., Grummer, J.A., Hennessey, K., Hsiao, J., Iranon, N., Jones II, L., Jordt, H., Keller, M., Lacey, M.E., Littlefield, C.E. … Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *PNAS, 117*(12), 6476-6483. doi: 10.1073/pnas.1916903117.

Tharayil, S., Borrego, M., Prince, M., Nguyen, K.A., Shekhar, P., Finelli, C., & Waters, C. (2018). Strategies to mitigate student resistance to active learning. *International Journal of STEM Education, 7*(5). https://doi.org/10.1186/s40594-018-0102-y

Thistlethwaite, J.E., Davies, D., Ekeocha, S., Kidd, J.M., MacDougall, C., Mathews, P., Purkis, J., & Clay, D. (2012). The effectiveness of case-based learning in health professional education. A BEME systematic review: BEME Guide No. 23, *Medical Teacher, 34*(6), 421-444. https://doi.org/10.3109/0142159X.2012.680939

Thompson, A.R. & O'Loughlin, V.D. (2015). The Blooming Anatomy Tool (BAT): A discipline-specific rubric for utilizing Bloom's Taxonomy in the design and evaluation of assessments in the anatomical sciences. *Anatomical Sciences Education, 8,* 493-501.

University at Buffalo Libraries (n.d.) National center for case study teaching in science. https://sciencecases.lib.buffalo.edu/

VanPutte, C.L. & Seeley, R.R. (2022*). Seeley's anatomy & physiology.* New York, NYT: McGraw-Hill.

Verkade, H., Mulhern, T. D, Lodge, J. M., Elliott, K., Cropper, S., Rubinstein, B., Horton, A., Elliott, C., Espiñosa, A., Dooley, L., Frankland, S., Mulder, R., and Livett, M. (2017). Misconceptions as a trigger for enhancing student learning in higher education: A handbook for educators. Melbourne: The University of Melbourne.

Voon, X.P., Wong, L.H., Looi, C.K., & Chen, W. (2020). Constructivism-informed variation theory lesson designs in enriching and elevating science learning: Case studies of seamless learning design. *Journal of Research in Science Teaching, 57,* 1531-1553.

Yadav, A., Shaver, G.M., & Meckl, P. (2010). Lessons learned: Implementing the case teaching method in a mechanical engineering course. *Journal of Engineering Education, 99*(1), 55-69.

Wieman, C. (2017). *Improving how universities teach science: Lessons from the Science Education Initiative*. The President and Fellows of Harvard College.

Zahara, M.N., Hendrayana, A., & Pamungkas, A.S. (2020). The effect of problem-based learning model modified by cognitive load theory on mathematical problem solving skills. *Hipotenusa: Journal of Mathematical Society, 2*(2), 41-55.

Appendix A

Blooming Anatomy Tool

The Blooming Anatomy Tool (BAT)

	Lower order		Higher order	
Bloom's level	**Level 1 (Knowledge)**	**Level 2 (Comprehension)**	**Level 3 (Application)**	**Level 4 (Analysis)**
Distinguishing features of questions	• Questions are straight forward with answers likely stated verbatim in notes or text • Question usually not placed in a clinical context • Students not required to make independent connections from the information		• Anatomic information may be placed in a clinical scenario or a new setting (although not all clinical questions are higher order) • Students must interpret and make independent connections from the information	
Key skills assessed	Identify, recall, repeat, memorize	Describe or distinguish	Infer or predict	In addition to infer or predict: interpret, judge, critique, or analyze
Types of anatomical information assessed	• Basic definitions • Facts • Straightforward recall	• Anatomical concepts • Basic spatial organization • Basic understanding of pathways, blood supply, and innervation	• Interaction between two or more body systems • Functional aspects of anatomical features beyond memorization	• Interaction between two or more body systems and applying information to a potentially new situation • Interpretation of anatomical images • Potential to use clinical judgment
Characteristics of multiple choice questions	• Only requires information recall • Student may memorize answer without understanding process • Knowing the "what" but not understanding the "why"	• Straightforward question, but more than a simple definition • Visualization of a region • Image questions asking to ID a structure without requiring a full understanding of the relationship of all of parts	• Apply information in a new context • Connect multiple pieces of information independently (ex. several "steps" or "links" with the data must be understood in order to answer the question correctly) • No clinical judgment is required	• Using information in a new context • Possibility for clinical judgment • Student required go through multiple "steps" and apply those connections to a situation • Interpreting an image or data and applying information to a situation
Sample multiple-choice questions	The carpal tunnel is located deep to which of the following structures in the upper limb? A. Palmar interossei **B. Flexor retinaculum** C. Extensor retinaculum D. Cubital fossa E. Thenar eminence	Which of the following structures passes through the carpal tunnel? A. Deep branch of the radial nerve B. Tendon of palmaris longus **C. Tendon of flexor pollicis longus** D. Deep branch of the ulnar nerve E. Anterior interosseous artery	Pressure in the carpal tunnel would most likely affect which of the following? A. Palmar interossei B. Sensory innervation of the central palm C. Movement of hypothenar muscles D. Sensory innervation of the 5^{th} digit **E. Movement of thenar muscles**	A 60-year-old male presents to the hospital for a carpal tunnel release surgery. During the procedure, the surgeon accidently cuts the nerve traveling superficial to the flexor retinaculum. As a result, the patient would most likely have A. Wasting of the thenar eminence **B. Sensory loss to the central palm** C. Weakness in wrist flexion D. Sensory loss to the tip of the thumb E. Weakness in adduction of the 2^{nd} digit
Justification for scoring in example question	Requires only basic understanding of forearm/wrist anatomy.	Students must visualize structures located near the carpal tunnel and discriminate between distractors.	Two independent steps are required. Students must recall that the median nerve travels through the carpal tunnel and know what structures it innervates.	All steps described in the previous three questions are required. In addition, students must related detailed understanding of the anatomic organization of the region to a clinical presentation associated with nerve damage.

Note: Bold face font indicates correct answers

(Thompson & O'Loughlin, 2015)

Appendix B

Exam 1 Multiple-Choice Questions

Exam #1

Traditional Instruction (Lecture) Questions

1. If the thoracic cavity was cut along the midsagittal plane, which of the following descriptions of the two halves would be accurate? (**Apply**)
   A. The midsagittal cut would create an anterior half that contained portions of the lungs and heart and a posterior half that contained the spinal cord.
   B. The midsagittal plane would produce a medial half and a lateral half, each containing a lung.
   C. The midsagittal plane would produce a right half that contained one lung and a left half that contained a lung and most of the heart.
   D. The midsagittal plane would produce an inferior half that contained portions of the heart and portions of both lungs and a superior half that contained portions of the lungs and the thymus.

2. If one of the functions of the capillaries is to supply body cells with oxygen and nutrients, you would expect the capillary walls to consist of: (**Apply**)
   A. connective tissue.
   B. keratinized epithelium.
   C. stratified squamous epithelium.
   D. simple columnar epithelium.
   E. simple squamous epithelium.

3. A researcher discovered a sensory receptor that detects decreasing oxygen concentrations in the blood. According to the principles of negative feedback, it is likely that stimulation of this sensory receptor will produce which of the following types of responses? (**Analyze**)
   A. A decrease in heart rate
   B. An increase in the respiratory rate
   C. An increase in physical activity
   D. Unconsciousness
   E. Both a decrease in heart rate and an increase in the respiratory rate will occur.

4. A glandular secretion has been analyzed and indicates the presence of cytoplasmic components that include DNA and nuclear proteins. This indicates ________ mode of secretion. (**Analyze**)
   A. holocrine B. merocrine C. autocrine D. eccrine

Case-based Instruction Questions

1. Na (atomic no. 11) reacts with Cl (atomic no. 17) to become stable. In the reaction, Na will ________, while Cl will ________. (**Apply**)
   A. accept one electron; give up one electron
   B. give up one proton; accept one proton
   C. share one electron with chlorine; share one electron with sodium
   D. become an anion; become a cation
   E. give up one electron; accept one electron

2. A cell that produces many proteins for secretion would have large numbers of (**Apply**)
   A. rough ER and Golgi apparatus.
   B. lysosomes and Golgi apparatus.
   C. Golgi apparatus and microvilli.
   D. ribosomes and centrioles.
   E. mitochondria and cilia.

3. Prions are pathogenic proteins that are linked to different neurodegenerative diseases. Investigations of some have indicated that normal cellular proteins and prions have the same amino acid sequence. How is this possible? (**Analyze**)
   A. Though the primary structure is the same between the prion and the normal cellular protein, differences at higher levels (secondary or tertiary) alter protein activity.
   B. The amino acid sequence is not important to the function of the protein because protein function is completely determined by the pH of the environment.
   C. The double helix structure of proteins is easily altered by separating the nitrogenous bases holding the strands together, allowing for a protein to act as a prion.
   D. The amino acids of the prion must have more hydrophilic sections, causing it to interact with the lipids of the plasma membrane and disrupting cell activity.

4. You are looking at a cell with the electron microscope and you notice the following characteristics: presence of many mitochondria and lysosomes; few, if any, Golgi apparatus; and many ribosomes. Which of the following is the most likely function of that cell? (**Analyze**)
   A. Secretion of lipids
   B. Intracellular digestion
   C. DNA replication
   D. Modification of protein
   E. Absorption of nutrients

Appendix C

Data Collection Chart for Multiple-Choice Questions

Exam #:

Date:

	Traditional Instruction Questions			Case-Based Instruction Questions			Overall Exam Score (50 possible)
Student #	Apply (2 possible)	Analyze (2 possible)	Total (4 possible)	Apply (2 possible)	Analyze (2 possible)	Total (4 possible)	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							

Appendix D

ELIPSS Critical Thinking Rubric

Critical Thinking	Evaluating, analyzing, and/or synthesizing relevant information to form an argument or reach a conclusion supported with evidence.

Category	0	1	2	3	4	5
Evaluating		**Minimally** determined the relevance and reliability of information that might be used to support a conclusion or argument		**Partially** determined the relevance and reliability of information that might be used to support a conclusion or argument		**Extensively** determined the relevance and reliability of information that might be used to support a conclusion or argument
Analyzing		**Inaccurately** interpreted information to determine meaning and to extract relevant evidence		Interpreted information to determine meaning and to extract relevant evidence **with some errors**		**Accurately** interpreted information to determine meaning and to extract relevant evidence
Synthesizing		**Inaccurately** connected or integrated information to support an argument or reach a conclusion		Connected or integrated information to support an argument or reach a conclusion **with some errors**		**Accurately** connected or integrated information to support an argument or reach a conclusion
Forming Arguments (Structure)		Made a claim and provided **incomplete** evidence to support it.		Made a claim and provided **partial** evidence to support it.		Made a claim and provided **complete** evidence to support it.
Forming Arguments (Validity)		The claim, evidence, and reasoning were **minimally** consistent with accepted disciplinary ideas and practices		The claim, evidence, and reasoning were **partially** consistent with accepted disciplinary ideas and practices		The claim, evidence, and reasoning were **fully** consistent with accepted disciplinary ideas and practices
Comments:						

Fig. 2 Rubric for assessing critical thinking

(Reynders et al., 2020)

Appendix E

Case Study Review Homework Assignment

Name: _____________________________ My role in this case study: _______________

Case study partners:

___________________________________ ___________________________________

___________________________________ ___________________________________

In a well-written paragraph, answer the three following questions concerning the case study that we completed in class:

1. What was the main question the case study attempted to answer?
2. What were the main points of data (or information) that were essential to know in order to answer the question? (**Evaluating**)
3. How did this information relate to the question that the case study attempted to answer? (**Analyzing**)
4. Explain how this data/information was used to answer the question. (Be sure to specifically explain <u>how</u> and <u>why</u> the data/information provided the answer to the question.) (**Synthesizing**)

Appendix F

Rubric for Case Study Homework Evaluation

Student Name:

Name of case study:

Critical Thinking Rubric – Case Study Analysis						
Category	0	1	2	3	4	5
Evaluating		**Minimally** determined the relevance of information that might be used to support a conclusion or argument		**Partially** determined the relevance of information that might be used to support a conclusion or argument		**Extensively** determined the relevance of information that might be used to support a conclusion or argument
Analyzing		**Inaccurately** interpreted information to determine meaning and to extract relevant evidence		Interpreted information to determine meaning and to extract relevant evidence **with some errors**.		**Accurately** interpreted information to determine meaning and to extract relevant evidence.
Synthesizing		**Inaccurately** connected or integrated information to support an argument or reach a conclusion.		Connected or integrated information to support an argument or reach a conclusion **with some errors**.		**Accurately** connected or integrated information to support an argument or reach a conclusion.

Total score (out of 15): ______

Appendix G

Chapter 6 EOC Rubric

Instructor response	5 points	4 points	3 points	2 points	1 point	0 points
To answer the question, we need to know what calcium does in the body (what processes are impacted by calcium). In addition, it is important to know which hormones that control the process, which organs monitor calcium levels, and the organs that respond when the level is inappropriate.	Extensively determined the relevance of information that might be used to support a conclusion or an argument.	Missing one portion of the answer.	Partially determined the relevance of information that might be used to support a conclusion or argument.	Missing several elements of the answer.	Minimally determined the relevance of information that might be used to support a conclusion or argument.	Student did not answer question.
Each feedback mechanism in the body has a receptor/sensor that recognizes a change in the variable (in this case calcium), a response (in this case a hormone), and an effector organ that causes the change to occur. To understand how calcium homeostasis is maintained, you need to know each of these components and how they work.	Accurately interpreted information to determine meaning and to extract relevant evidence.	Missing one portion of the answer.	Interpreted information to determine meaning and to extract relevant evidence with some errors.	Missing several elements of the answer.	Inaccurately interpreted information to determine	Student did not answer question.
Calcium is controlled in the body by 3 hormones: PTH, calcitriol, and calcitonin. Cells in the parathyroid detect inappropriate levels of calcium in the blood and respond by releasing a hormone to reverse it. The hormones stimulate organs (bone, kidney, and intestine) to either release more calcium into the blood or remove calcium. A with elevated blood calcium will experience "bones" (pain in bones, fractures), "stones" (kidney stones), "groans" (abdominal pain and constipation), and "moans" (psychological impairment and depression).	Accurately connected or integrated information to support an argument or reach a conclusion.	Missing one portion of the answer.	Connected or integrated information to support an argument or reach a conclusion with some errors.	Missing several elements of the answer.	Inaccurately connected or integrated information to support an argument or reach a conclusion	Student did not answer question.

Appendix H

Example of Case Study Assigned After Didactic Units

Case STUDY 2.1

Cyanide Poisoning

Although Becky was rescued from her burning home, once outside she felt faint and dizzy with a terrible headache and vomiting. The first responder, Bill, took her vital signs and suspected that she might be suffering from cyanide poisoning. Inhalation of smoke from burning rubber and plastic in household fires is the most common cause of cyanide poisoning. In a house fire, the two main toxic gases are hydrogen cyanide and carbon monoxide. Both are very dangerous and can be hard to diagnose in the field. At high levels, cyanide leads to cardiac arrest and death if not quickly treated. Cyanide can be lethal because it interferes with ATP production in mitochondria (see **chapters 3** and **25**). Without sufficient ATP, cells die because there is inadequate energy for anabolic chemical reactions and other energy-requiring processes. The heart and brain are especially susceptible to cyanide poisoning due to their relatively high energy requirements. Fortunately, Bill's quick diagnosis allowed successful treatment of Becky by injection of vitamin B_{12} to bind and detoxify the cyanide.

(VanPutte & Seely, 2020)

Appendix I

Student Assessment of Learning Gains (SALG) survey questions

How much did each of the following activities help your learning about the topic covered in that activity?

	I do not remember this case study	Provided no help	Helped a small amount	Helped a moderate amount	Helped a good amount	Helped a great amount
1. Completing the case study about the different types of chemical bonds.	0	1	2	3	4	5
2. Completing the case study about the different functions of cell organelles.	0	1	2	3	4	5
3. Completing the case study about the skeletal system.	0	1	2	3	4	5
4. Completing the case study about muscle physiology (how muscles work).	0	1	2	3	4	5
5. Completing the case study about nervous physiology (how nerves work).	0	1	2	3	4	5

OVERALL, how much did each of the following aspects of the class help your learning?

	Did not complete	Provided no help	Helped a small amount	Helped a moderate amount	Helped a good amount	Helped a great amount
6. Reading the textbook.	0	1	2	3	4	5
7. Listening to lectures by the professor.	0	1	2	3	4	5
8. Completing case studies.	0	1	2	3	4	5
9. Completing lab activities.	0	1	2	3	4	5

OVERALL, how much did each of the following aspects of the class help you to understand the connections between scientific concepts and other aspects of your everyday life?

	Did not complete	Provided no help	Helped a small amount	Helped a moderate amount	Helped a good amount	Helped a great amount
10. Reading the textbook.	0	1	2	3	4	5
11. Listening to lectures by the professor.	0	1	2	3	4	5
12. Completing case studies.	0	1	2	3	4	5
13. Completing lab activities.	0	1	2	3	4	5

(Questions modified from Bonney, 2015)