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Enhancing Critical Thinking in Clinical Laboratory Students: A Multimodal Model

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Enhancing Critical Thinking Skills in Clinical Laboratory Students:
A Multimodal Model

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

by

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Abstract

ENHANCING CRITICAL THINKING SKILLS IN CLINICAL LABORATORY STUDENTS: A MULTIMODAL MODEL

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

Virginia Commonwealth University, 2014.

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The purpose of this study was to improve critical thinking skills in clinical laboratory technologists through the development, implementation, and assessment of a multimodal model targeting critical thinking skills. Clinical laboratory technologists influence patient care through the testing of laboratory samples. Employers of these entry level professionals identified a need for improved critical thinking skills. This quasi-experimental study aimed to design a multimodal critical thinking model, implement the model into the clinical laboratory educational curriculum, and assesses this skill set for students in a pre-test / post-test format. The model was delivered and assessed for 47 clinical laboratory students at the University of Texas M.D. Anderson Cancer Center's

School of Health Professions. Based on numerical results for the Health Science Reasoning Test (HSRT), no significant difference in critical thinking skills was observed for clinical laboratory students before and after the integration of the multimodal model targeting this skill set into the curriculum. For the purpose of this study, critical thinking was defined as the ability to effectively evaluate and interpret data, apply existing knowledge to solve problems in new situations, demonstrate creativity and resourcefulness in learning, and problem solving, and effectively and persuasively communicate findings. Further analysis of the results indicated that junior and community college students were more likely to improve their HSRT scores after completion of the multimodal model than 4-year university and bachelor level students. Findings also suggest a positive relationship between GPA and improved HSRT scores. The amount of time as student spent on each assessment was directly related to success, and an inverse relationship was observed for usage of the model reference material. Further studies are needed to ensure model validity and generalizability of findings. Additionally, HSRT categorical results indicate the need for model modifications to better target the areas of deduction and inference. The online, asynchronous format may benefit from the addition of mandated discussion boards, and requiring assessment and evaluation completion may reduce the effects of lack of effort due to cognitive fatigue observed for this study.

Chapter One - Introduction

Overview

Critical thinking skills are essential for clinical laboratory technologists to succeed as professionals in a continually evolving clinical work environment. Clinical laboratory technologists analyze patient samples to generate test results that assist in directing patient care. The accuracy of these test results is crucial to the delivery of appropriate medical treatment and necessary to achieve positive patient outcomes. However, employers of entry level professionals reported that improved critical thinking skills will lead to a better quality of care for patients. The purpose of this study was to improve critical thinking skills in clinical laboratory technologists through the development, implementation, and assessment of a multimodal model targeting this skill set. This chapter will provide background on the professions categorized under the heading clinical laboratory technology and describe the need for improved critical thinking skills for students and professionals in these disciplines. In addition, this chapter will describe the aims and hypothesis of this study, highlight the significance, and introduce the theoretical framework used in the study design. Furthermore, this chapter will introduce the development, implementation, and assessment plan for a multimodal model aimed at enhancing this skill set. This chapter will also summarize the data source of this study and briefly describe the additional chapters related to this proposal.

Background

Under the auspices of laboratory medicine, clinical laboratory technologists perform laboratory tests critical to the health care system. For the purposes of this study, clinical laboratory technologists include medical laboratory scientists (MLS), molecular genetic technologists (MGT), cytogenetic technologists (CG), cytotechnologists (CT), and histotechnologists (HTL). These professionals perform tests to aid in prevention, detection, and treatment of disease. The focus of this study will be on the technologist level in which the practitioner typically holds a bachelors level degree and is certified in their specific discipline through the American Society for Clinical Pathology Board of Certification (ASCP BOC). MLS, also known as clinical laboratory scientist (CLS) and medical technologist (MT) may be a certified generalist who has been trained in hematology, microbiology, chemistry, blood banking, and immunology or trained in only one of these categorical areas. MGT is also referred to as diagnostic molecular scientist (DMS); professionals in this field hold a certification in molecular biology (MB). CG, HTL, and CT each hold certifications related to their specific disciplines.

Although there are various routes by which individuals may become eligible for certification through ASCP BOC, the most common route includes completion of an accredited program. Programs for MLS, MGT, CG, and HTL are accredited by the National Accrediting Agency for Clinical Laboratory Sciences (NAACLS), while CT programs are accredited by the Commission on Accreditation for Clinical Laboratory Programs (CAAHEP). The accrediting bodies put forth a set of guidelines for each discipline to follow when constructing and developing programmatic course content. In

addition, these accrediting bodies monitor the success of each accredited program in its ability produce competent graduates entering the specified profession, through regular reviews and visits to each institution. The goal of these accrediting bodies is to uphold high standards for educating individuals that will be entering the clinical laboratory technology professions upon graduation.

Test results generated by clinical laboratory professions directly impact patient care and outcomes by providing invaluable data to assist with the patient diagnosis, treatment, prevention, and monitoring of disease. MLS professionals use sophisticated biomedical instrumentation and technology, computers, as well as methods requiring manual dexterity to perform laboratory testing on blood and body fluids. These tests encompass disciplines such as clinical chemistry, hematology, immunology, immunohematology, microbiology, and molecular biology. The results generated from these tests assist in diagnosing and monitoring treatment for cancer, heart attacks, diabetes, infectious mononucleosis, bacterial and viral infection, and drugs of abuse (American Society for Clinical Laboratory Science, 2012).

Like other clinical laboratory professionals, MGT and CG work independently to implement and troubleshoot established procedures, prepare appropriate specimens for analysis, perform analyses, integrate data, and report results. MGT utilize nucleic acids to discover relationships between genetics and personal health and focus on applications related to prenatal and pre-implantation diagnosis, risk assessment for familial cancer, diagnosis of neurological disorders, evaluation of malignant and hematologic disorders for diagnosis or staging of disease, identification of microbial agents, and forensics (Association of Genetic Technologists, 2012). CG perform

chromosomal analyses to provide data to assist in decisions related to prenatal diagnosis, diagnosis of congenital chromosomal abnormalities, diagnosis and risk of familial chromosomal abnormalities, and evaluation of malignant and hematologic disorders for diagnostic and prognostic purposes (Association of Genetic Technologists, 2012).

Histotechnologists prepare thin slices of tissue for microscopic examination in order to assist in the scientific investigation of establishing and confirming a patient diagnosis. These professionals use techniques such as grossing and fixation, processing, embedding, sectioning, and staining to prepare specimens for examination (National Society for Histopathology, 2012). Cytotechnologists distinguish between normal and abnormal specimens by analyzing cellular patterns and subtle changes in both the nucleus and cytoplasm of cells while correlating with the patient's clinical history. They are solely responsible for the microscopic interpretation of Pap smears interpreted as normal, and are responsible for conducting preliminary interpretations of specimens from other sites, such as lung, bladder, body cavities, central nervous system, gastrointestinal track, liver, lymph nodes, thyroid, salivary glands, and breast. These professionals collaborate with pathologists to diagnosis benign and infectious processes, precancerous lesions, and malignant disease (American Society for Cytotechnology, 2012).

In order to accurately perform these tests, all clinical laboratory technologists must have an extensive theoretical knowledge base. They not only perform laboratory procedures, but also evaluate and interpret results, integrate data, problem solve, consult, conduct research, and develop and validate new testing methods (American

Society for Clinical Laboratory Science, 2012). In addition, all clinical laboratory technologists monitor test quality and strive to provide results in a timely, safe, and cost effective manner. The test results generated help save patients' lives by allowing clinicians to provide the necessary and appropriate treatment as quickly as possible.

Formal education programs created to meet the goal of producing quality professionals, focus on training students in both didactic theory and hands-on laboratory skills. However, there is no direct focus or requirement for implementing methods to improve critical thinking skills in accredited clinical laboratory technology programs. Results from a recent survey of educators, practitioners, and managers of clinical laboratory technologists to assess perceptions of future job expectations and skills expected of entry-level and experienced employees indicate that entry-level expectations were primarily scientific and technical. However, participants of this survey agreed that future CLS practitioners will spend less time performing laboratory tests and more time solving problems (Beck & Doig, 2002). The importance of problem solving skills and the ability to think critically have been identified as key characteristics of clinical laboratory professionals (Beadling & Vossler, 2001; Beck & Boig, 2007; Greer, 2008).

Research Problem

Although the ability to think critically has been identified as a pivotal trait of clinical laboratory professionals (Kenimer, 2002), employer focus groups conducted by the University of Texas M.D. Anderson Cancer Center's School of Health Professions (UTMDACC-SHP) on the topic of critical thinking in clinical laboratory professionals found that better critical thinking skills are needed to improve laboratory productivity and

produce better quality of care for patients (Greer, 2008). The employers participating in these focus groups not only hire graduates from the UTMDACC-SHP programs but from other accredited programs throughout the country. Thus, there appears to be mismatch between what is required of professionals entering these fields and the skill sets they have obtained prior to employment. Additionally, the bodies that set the educational guidelines for these programs do not directly enforce the enhancement of this skill set.

There is a growing need for clinical laboratory technologists to monitor performance parameters, classify and track laboratory errors, and determine the necessity of laboratory testing. As these demands increase, the need for clinical laboratory technologists to have a good set of critical thinking skills will become more important (Beadling & Vossler, 2001). In addition, the ability to think critically is important for routine laboratory tasks such as troubleshooting, resolving problems, and multitasking (Beck & Doig, 2007). Focus groups including employers of these professionals have expressed concern of a disconnect between student learning and the real world (Greer, 2008).

Furthermore, psychology literature shows that even though students may understand a basic concept, less than 30% are able to apply that knowledge to solve a new problem (Norman, 2009). Without the ability to transfer knowledge from one idea to another, critical thinking and problem solving are not occurring. Transfer explains a student's ability to apply information learned in one situation to another situation, while problem solving requires the use of transferred knowledge to solve a problem (Ormrod, 1999). Critical thinking is a more complex concept that involves both transfer and problem solving while also requiring that the thinker effectively evaluate and the

interpret data, evaluate ideas and other points of views, demonstrate creativity and resourcefulness in learning, and effectively and persuasively communicate the findings (Quality Enhancement Plan, 2010).

It has been reported that many times, teaching is not directed at designing activities to specifically foster critical thinking (Vacek, 2009). Without the proper learning activities, students are unable to gain the critical thinking skills needed to apply information acquired in the education setting to on the job situations. In order for students to obtain this knowledge, it must be incorporated into the curriculum.

Although there is no single definition of critical thinking agreed upon in the literature, there is much overlap between those that exist. Some of the differences can be explained by the statement that not every cognitive process is critical thinking and not every thinking skill is a critical thinking skill. Additionally, critical thinking is part of a group of related forms of higher order thinking and the relationship between these skills is yet to be fully investigated or characterized (American Philosophical Association, 1990). However, two continually reoccurring ideas in the literature related to critical thinking are assessment and judgment (Fesler-Birch, 2005).

For the purpose of this project, a working definition of critical thinking was adopted. The definition was generated by the University of Texas M.D. Anderson Cancer Center's School of Health Professions and aligns well with other critical thinking definitions identified in the literature. Additionally, it was generated through an extensive literature search and statements made during numerous focus groups. For purposes of this study, critical thinking includes the ability to 1) effectively evaluate and interpret data; 2) apply existing knowledge to solve problems in new situations with emphasis on

evaluating ideas and other points of view; 3) demonstrate creativity and resourcefulness in learning and problem solving; and 4) effectively and persuasively communicate findings (Quality Enhancement Plan, 2010).

Purpose of Study

The purpose of this study was to improve critical thinking skills in clinical laboratory technology students through the use of a multimodal model. The study was designed to address the following three specific aims related to one hypothesis.

- **Null Hypothesis:** There is no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum.
- **Alternative Hypothesis:** There is a significant difference in critical thinking skills for clinical laboratory students before and after integration of a multimodal model targeting this skill set into the curriculum.
 - *Aim 1:* To design a multimodal teaching model to enhance critical thinking skills in clinical laboratory technology students.
 - *Aim 2:* To implement a multimodal model into clinical laboratory technology student curriculum.
 - *Aim 3:* To evaluate the success of the multimodal model in improving critical thinking skills of students in clinical laboratory technology programs.

Success of this model in improving critical thinking in clinical laboratory technology students would assist in bridging the gap between the critical thinking skill set currently obtained by students completing an education through an accredited

institution and the level of critical thinking skills needed by entry level professionals in the work environment.

Introduction to Theoretical Framework

Theories related to critical thinking and the related ideas of transfer and problem solving have evolved over time from perspectives of behaviorism to cognitivism and finally constructivism. The focus progressed from behaviorism theories in which environmental conditions were simply observed to explain the learning process to cognitive theories which focused on explaining how people perceive, interpret, remember, and think about the environmental events that they experience (Ormrod, 1999). The progression from cognitive theories to constructivist theories occurred when theorists observed that people do not just process information directly from their environment but instead construct knowledge from this information (Ormrod, 1999).

Constructivism is designed to promote an authentic and realistic experience for each learner by encouraging the use of multiple pathways and processes when approaching a problem (Bossard, Kermarrec, Buche, & Tisseau, 2008). The Theory of Cognitive Flexibility is a constructivist theory focusing on cognitive flexibility with an emphasis on the transfer of knowledge and skills for applications in new situations. The idea of cognitive flexibility is to provide the learner with the ability to reconstruct knowledge in a variety of ways depending on the demands of a changing situation with a goal of understanding these evolving scenarios (Spiro, Vispoel, Schmiyz, 1987). Central to this theory is the use of real world context to promote transfer of basic knowledge to dynamic situations.

An aim of the Cognitive Flexibility Theory is to advance learning through the development of flexible representations of knowledge to assist in promoting a meaningful understanding of the material and allow for the use of this knowledge in new situations (Ludwig, 2000). Constructs central to this theory include anchored instruction, situated knowledge, constructivism, adaptivity, multimodality, transfer, knowledge representation, problem-based learning, case-based teaching and learning, analogy and assessment. In addition, this theory ties multimodality, in terms of multimedia, hypermedia, and adaptivity to learning and instruction, to critical thinking enhancement (Honegger, 2007; Siegel, et al, 2000).

The multimodal model for this study was designed to include teaching strategies from the Cognitive Flexibility Theory in an interactive web-based model. The model contains multiple modules designed to address each area of the critical thinking definition adopted for this project. Additionally, the model was delivered to clinical laboratory technology students in an independent, self-guided manner and assessed with the Health Science Reasoning Test (HSRT) provided by Insight Assessments. The model included an introduction to critical thinking, followed by four modules.

The modules utilized scaffolding in a way that allows the learner to grasp the basic skills being addressed before proceeding into more integrated scenarios. The complexity of learning within each module builds, while being supported by multimedia links and reference material. Socratic questioning was used to guide the initial thought process, while modeling and feedback were provided to supplement this process. The model was centered on case studies, problem scenarios, and design projects using content in the field of critical laboratory technology; however, the focus is on the process

and not the content. The HSRT was administered in a pre-test / post-test format to evaluate the students' critical thinking skills in the areas of analysis and interpretation, inference, evaluation and explanation, inductive reasoning and deductive reasoning (Insight Assessment, 2011).

Summary of Data Sources

A primary data source was used to assess the aims of this study and test the hypotheses proposed for this study. The subjects were composed of undergraduate junior year students enrolled in a clinical laboratory technology at the UTMDACC-SHP. Although the model is self-paced, it is designed to cover no more than a 14-week period in the fall semester. A difference between pre-test and post-test HSRT scores was evaluated for significance. Success of the model was determined by a significant pre-test / post-test score change for the consenting students. Although this study was conducted at a single institution, because of the online nature of the design, the multimodal model may have the potential to be implemented into other clinical laboratory technology programs with web-based capabilities. With slight modifications, other allied health professions settings.

Summary and Overview of Remaining Chapters

As the majority of clinical laboratory technologists receive formal training from an accredited educational facility, it was important to address the gap between the required curriculum content and the skill set needed to succeed in this profession. Critical thinking and problem solving skills have been identified as critical components of the clinical laboratory (Beck & Doig, 2002; Greer, 2008). However, surveys have indicated a need for improvement of these skills in entry level technologists (Greer, 2008). Although

the NAACLS and CAAHEP Standards require curricula to include problem-solving, troubleshooting, and interpretation of results, the Standards do not include guidelines on how these skills should be enhanced, implemented, or assessed.

The purpose of this study was to improve critical thinking in clinical laboratory technology students through the use of a multimodal model. The model utilized constructs of the Cognitive Flexibility Theory to direct the development of targeted interventions designed to improve four key components of critical thinking. This framework has yet to be used in this field; however, the application of this theory and related constructs has been successful in a number of other allied health professions. Additionally, the integration of interactive, web-based, multimodal, case studies and problem scenarios has been demonstrated in other professions (Siegel, et al, 2000; Ludwig, 2000).

Literature review and methods chapters will follow. The literature review chapter is used to summarize the current literature addressing this topic and to fully investigate studies related to this idea, as well, as to point out gaps pertinent to the literature that may exist. In addition, the methods chapter includes a detailed explanation of the specific study components, including research design, population and sample, interventions, instrument, data collection procedures, data analysis, and study limitations.

Chapter Two - Literature Review

Chapter Introduction

Few published articles focus specifically on enhancing critical thinking skills for clinical laboratory students. Therefore, a review of the literature assessing the need for improved critical thinking skills in clinical laboratory students contains information on a variety of health care professions in which more data has been published. This review chapter begins by identifying existing critical thinking definitions and skill sets in the literature and those adopted for this project. This chapter also covers the evolution and connection of concepts and theories related to critical thinking.

In addition, this section evaluates the importance of critical thinking skills in health care professions, including the clinical laboratory. This chapter also focuses on the relationship between the need for critical thinking skills in the professions and the level of skills provided by educational programs and the limitations regarding the implementation of these skills into the educational curriculum. Additionally, this chapter provides information on constructs related to the Cognitive Flexibility Theory and how these constructs have been used to improve critical thinking skills in health care professionals, specifically focusing on clinical laboratorians. Finally, literature related to methods that have been developed for enhancing critical thinking skills, implementation structures, and tools used for assessing the success of these methods is discussed.

The following review serves to understand the published data related to this proposed study and the gaps in knowledge that exist surrounding this topic.

Defining Critical Thinking Skills

Definitions in the literature. The concept of critical thinking is not inherently obvious; therefore, a number of definitions can be found in the literature. These definitions range from comprehensive explanations, such as that by Scriven and Paul (1987), describing critical thinking as "... an intellectually disciplined process of actively and skillfully conceptualizing, applying, and analyzing, synthesizing, and or evaluating information gathered from, or generated by observation, experimentation, reflection, reasoning, or communication, as a guide to belief and action" to more abstract descriptions, such as one offered a couple of years later by Paul, Binker, Adamson, and Martin (1989) which described critical thinking as "... the art of thinking about your thinking while you are thinking in order to make your thinking better...". Although these definitions differ greatly in wording, the underlying description of critical thinking is similar. The definition put forth by Scriven and Paul (1987) was adopted by the National Council of Excellence and explicitly outlines a number of skills needed to achieve the action described by Paul, Binker, Adams, and Martin (1989).

Many of the concepts of critical thinking included in the comprehensive definition put forth by Scriven and Paul in 1987 come from Bloom's Taxonomy (1956). Concepts of Bloom's Taxonomy include application, analysis, synthesis, and evaluation; these concepts were later updated by Anderson (2001) to include applying, analyzing, evaluating, and creating. However, additional concepts can also be attributed to earlier critical thinking definitions such as that offered by Dewey (1938) in which the idea of

critical thinking is explained by reflective thinking where by the thinker is able to extract the overall meaning from an experience and apply it to a subsequent experience. A few years later, Glaser (1941) described critical thinking as the ability to think critically with an attitude of being disposed to consider the thinker's experience in regards to a problem, the knowledge of methods of logical inquiry and reasoning, and the ability to apply those methods. This was a modification of the earlier focus on fair-mindedness put forth by Watson (1925).

Subsequently, Ennis (1962) lists three components of critical thinking as logic, criterion, and pragmatism. He explains logic as the ability to evaluate the relationship between the meaning of the words and a statement, criterion as having the knowledge to evaluate the statement, and pragmatism as being able to evaluate the purpose and to decide whether the statement is appropriate for the purpose (Ennis, 1962). Later, Siegel (1980) again draws on the common thread of assessment and judgment by describing a critical thinker as a thinker that uses reasoning to make assessments and judgments while understanding the principles used in evaluating the process.

In a comparison between the scientific process and the critical thinking process, Logan (1987) finds an overlap between the involvement of analysis, synthesis, deduction, and inference. The 1990 American Philosophical Association's Delphi Report suggests that a critical thinker is one who is prudent in making judgments and focuses in inquiry (American Philosophical Association, 1990). This report described a list of cognitive skills and affective dispositions related to critical thinking. The cognitive skills include interpretation, analysis, evaluation, inference, explanation, and self-regulation, while the affective dispositions focus on attitudes to life and living and approaches taken

when dealing with specific issues, questions, or problems (American Philosophical Association, 1990). These skills overlap with a number of skills described in earlier critical thinking definitions.

In relation to the healthcare profession and specifically the nursing profession, the critical thinking definition was established to include the following 17 dimensions: analyzing, applying standards, confidence, contextual perspectives, creativity, discriminating, flexibility, information seeking, inquisitiveness, intellectual integrity, intuition, logical reasoning, open-mindedness, perseverance, predicting, self-reflection, and transforming knowledge (Scheffer & Rubenfeld, 2000). After an evaluation of available critical thinking definitions, Fesler-Birch (2005) concluded that regardless of the specific wording, two concepts related to critical thinking continually reoccurred, assessment and judgment. For the nursing profession, assessment, along with planning, implementation, and evaluation are necessary in patient care. Additionally, the patient care process requires the use of clinical judgment as a critical thinking thought process (Fesler-Birch, 2005).

Evaluation of definitions. To further validate the critical thinking skills and dispositions presented in the 1990 Delphi Report, an independent research study sponsored by the United States Department of Education was designed to conduct a national survey of educators, employers, and policy makers to determine the priority in regards to communication and thinking skills expected of college graduates. The critical thinking skill set and dispositions agreed upon in the 1990 Delphi Report were used in creating the survey. The findings of the survey indicated a strong national consensus

between the 1990 Delphi dispositions and skills and the communication and thinking skills expected for college graduates (Jones et al, 1994).

From the cognitive skill and disposition constructs described in the 1990 Delphi Report came two primary assessment tools for evaluating the level of these skills in test takers administered by Insight Assessment. The California Critical Thinking Skills Test (CCTST) was designed to address the cognitive skills, whereas, the California Critical Thinking Disposition Inventory (CCTDI) was designed to evaluate affective dispositions (Facione, Facione, & Giancarlo, 2000). The specific subsections assessed by the CCTST include, analysis and interpretation, inference, evaluation and explanation, inductive reasoning, and deductive reasoning (Insight Assessment, 2011). The CCTDI focuses on expressing beliefs, values, attitudes and intentions that relate to reflective formation of reasoned judgments (Insight Assessment, 2011).

There are a number of critical thinking assessment tools available and although many of the skills targeted by these tests overlap, they do not all have the exact same focus. Some are more cognitive in nature, while others are more dispositional. The Watson-Glaser Critical Thinking Appraisal (WGCTA) tool has been modified a number of times over the years. However, the original developer, Watson (1925), was focused on evaluating the fair-mindedness of a person, a dispositional dimension. In 1941, Glaser modified Watson's ideas to create a test with the ability to evaluate critical thinking abilities. The WGCTA was designed to assess five critical thinking skills, including inference, recognition of assumptions, deductions, interpretation, and evaluation of argument (Watson & Glaser, 1980). This modification by Glaser shifted the assessment tool to focus on cognitive measures. Many of the skills assessed by the

WGCTA are now similar to the cognitive skill set represented in the CCTST; however there are slight differences such as inductive reasoning for the CCTST and recognition of assumptions for the WGCTA.

More recently the definition of critical thinking was reevaluated by Scheffer and Rubenfeld, (2000) using the Delphi method with nursing educators. An international panel of nursing experts worked from 1995-1998 to establish a consensus definition of critical thinking for the nursing profession. The findings indicate 17 consensus critical thinking skills, including the following 7 cognitive component: analysis, applying standards, discriminating, information seeking, logical reasoning, predicting, and transforming knowledge and the following 10 affective components: confidence, contextual perspective, creativity, flexibility, inquisitiveness, intellectual integrity, intuition, open-mindedness, perseverance, and reflection. Of these 17 critical thinking dimensions, some overlap is seen with both the cognitive skills and affective dispositions described by the 1990 Delphi report; however, some differences are also evident (Scheffer & Rubenfeld, 2000; American Philosophical Association, 1990) such as the focus on creativity and intuition.

In 2000, the Tennessee Technological University (TTU) began investigating methods for assessing critical thinking skills in their graduating seniors. Unsatisfied with the available options due to questionable validity or narrow scopes, TTU decided to begin the process of developing their own assessment tool to expand the testing focus from verbal, categorical, analogical and hypothetical-deductive reasoning to also include formal reasoning skills of logic, mathematics, and problem solving. Three groups of faculty at the institution worked in teams to identify important critical thinking skills and

develop questions to measure these skills. This interdisciplinary committee identified a set of critical thinking skills that they found important for effective problem solving, life-long learning, and critically evaluating information (Stein, Hayes, & Unterstein, 2003).

The original skills described in this study were categorized into four main focus areas including the ability to evaluate information, examine ideas and other points of view, learn and problem solve, and communicate (Tennessee Tech University, 2008). An assessment tool, the Critical Thinking Assessment (CAT), was generated by TTU to measure this skill set established by that institution. Even though different wording was used to describe the skill set, links can be drawn between the TTU skill set, Bloom's and Anderson's Taxonomy, the 1990 Delphi Report and the 2000 nursing Delphi Study (Tennessee Tech University, 2008; Bloom, 1956; Anderson & Krathwohl, 2001; American Philosophical Association, 1990; Scheffer & Rubenfeld, 2000). The TTU description is most like Bloom's Taxonomy, with the focus primarily on the cognitive domain, as opposed to the combination of cognitive and affective dispositions included with the 1990 Delphi Report and 2000 nursing Delphi Study.

There are a number of similarities and overlapping themes observed among these critical thinking definitions and skill sets. The Delphi Report stated that not every cognitive process is critical thinking and not every thinking skill is a critical thinking skill (American Philosophical Association, 1990). In addition, critical thinking is part of a family of closely related forms of higher order thinking, such as problem solving, decision making, and creative thinking; however, the relationship between these skills has not yet been fully investigated and categorized (American Philosophical Association, 1990). Finally the report concludes that there is no single way to

reasonably group and subcategorize the critical thinking skill set (American Philosophical Association, 1990). This is evident by the variety of categories and lack of complete agreement seen in the literature.

Development of working definition. Recently, the University of Texas M. D. Anderson Cancer Center's School of Health Professions (UTMDACC-SHP) created a working definition of critical thinking. In generating this definition, a committee was formed to evaluate existing literature and conduct focus group sessions to elicit additional information. The literature review focused on definitions of critical thinking and related philosophy-based and psychology-based theories and definitions (Quality Enhancement Plan, 2010). Two focus groups were conducted for each group of students and alumni, faculty, and employers. The student and alumni group consisted of locally residing, current and past UTMDACC-SHP students. Of the eight undergraduate health professions programs included in the UTMDACC-SHP, the following three were represented: cytogenetic technology, molecular genetic technology, and radiation therapy in the student and alumni focus group. This group had a 92.3% response rate (n=24). The faculty group consisted of UTMDACC-SHP current, full-time faculty members. Of the eight programs, seven were represented in the faculty focus group including: medical laboratory science, cytogenetic technology, molecular genetic technology, histotechnology, cytotechnology, radiation therapy, and diagnostic imaging. This group had an 88.2% response rate (n=15). The employer group consisted of directors and employees from local hospitals and laboratories commonly involved with hiring and managing graduates of the UTMDACC-SHP. This group had a 100% response rate (n=13) (Greer, 2008).

Based on the information gathered from these focus group sessions and the literature search, the committee decided on a working definition that highlighted the need for students to become focused analyzers in their approach to information, while at the same time allowing for the development of a greater appreciation for the changing environment in information delivery (Quality Enhancement Plan, 2010). The UTMDACC-SHP faculty reviewed the committee's definition and agreed that it was appropriate for use across all health professions programs. The institution chose a definition that is practical in nature. The definition is not an abstract definition, but lists four components of critical thinking that align with the existing literature and also address the feedback generated from the focus groups, in terms of critical thinking needs for health professions students. In addition, the definition chosen includes components that can be targeted for delivery and assessment. The UTMDACC-SHP working critical thinking definition is as follows: critical thinking includes the ability to 1) effectively evaluate and interpret data; 2) apply existing knowledge to solve problems in new situations with emphasis on evaluating ideas and other points of view; 3) demonstrate creativity and resourcefulness in learning and problem solving; and 4) effectively and persuasively communicate findings (Quality Enhancement Plan, 2010).

Definitions compared. This working definition generated by UTMDACC-SHP falls in line with the skill set developed by TTU (Quality Enhancement Plan, 2010; Tennessee Tech University, 2008). The results of focus groups at UTMDACC-SHP provided a description of critical thinking skills that resembled many of the comments utilized at TTU for development of critical thinking skills. For this reason, UTMDACC-SHP selected a definition that included the four components of critical thinking

previously adopted by TTU. In addition, when comparing with Anderson's version of Bloom's Taxonomy, the cognitive skills of critical thinking outlined in the Delphi Report, and the UTMDACC-SHP working definition of critical thinking a number of comparisons can be drawn (Anderson & Krathwohl, 2001; American Philosophical Association, 1990; Quality Enhancement Plan, 2010).

The first component of the UTMDACC-SHP definition, effectively evaluate and interpret data, aligns closely with Anderson's Understanding component and the Delphi Report's Interpretation component. Support for the second component of the UTMDACC-SHP definition, apply existing knowledge to solve problems in new situations with emphasis on evaluating ideas and other points of view, can be found in Anderson's Applying component. The third component of UTMDACC-SHP definition, demonstrate creativity and resourcefulness in learning and problem solving, finds a counterpart with both Anderson's Creating component and the Delphi Report's Inference component. Finally, a parallel can be drawn between the fourth component of the UTMDACC-SHP definition, effectively and persuasively communicate findings, and the Delphi Report's Explanation component. Not all elements of Anderson's Taxonomy and the Delphi Report are included in the UTMDACC-SHP critical thinking definition (Anderson & Krathwohl, 2001; American Philosophical Association, 1990). Table 1 presents the alignments between each portion of the UTMDACC-SHP critical thinking definition with the components of Anderson's Taxonomy and the cognitive aspects of the 1990 Delphi Report (Quality Enhancement Plan, 2010; Anderson & Krathwohl, 2001; American Philosophical Association, 1990).

Table 1: *UTMDACC-SHP critical thinking definition alignment*

UTMDACC-SHP	Anderson's Taxonomy	Delphi Report
Effectively evaluate and interpret data	Understanding	Interpretation
Apply existing knowledge to solve problems in new situations	Applying	-----
Demonstrate creativity and resourcefulness in learning and problem solving	Creating	Inference
Effectively and persuasively communicate findings	-----	Explanation

Skill sets compared. In a number of the definitions provided in the literature, the specific critical thinking skills needed for critical thinking are included or later described by the author. In addition to a general skill set included with the definition or assessment tool, some publications include a breakdown of these skills into more descriptive terms or sub-skill descriptions (American Philosophical Association, 1990; Tennessee Tech University, 2008). In the 1990 Delphi Report the six skills were further explained with a set of sub-skills for each. Table 2 lists the cognitive skills and related sub-skills identified in the 1990 Delphi Report (American Philosophical Association, 1990).

Similarly, TTU subdivided their four main areas into four sub-areas describing a more specific set of skills for each. Although these are not the only two sets of critical thinking skills that have been subdivided into sub-skill sets, the 1990 Delphi Report was used in the development of the CCTST and CCTDI while the TTU set was used in the development of the CAT. While the CCTST and CCTDI assessment tools, along with others such as WGCTA have been used more frequently, the number of publications

Table 2: 1990 Delphi Report critical thinking skills and sub-skills

Skill	Sub-skills
Interpretation	Categorization
	Decoding significance
	Clarifying meaning
Analyze	Examining ideas
	Identifying arguments
	Analyzing arguments
Evaluation	Assessing claims
	Assessing arguments
Inference	Querying evidence
	Conjecturing alternatives
	Drawing Conclusions
Explanation	Stating results
	Justifying procedures
	Presenting arguments
Self-regulation	Self-examination
	Self-correction

utilizing the CAT to assess critical thinking is increasing. Table 3 lists the critical thinking skills and related sub-skills described by TTU (Tennessee Tech University, 2008).

When comparing these two sets of skills and sub-skills, TTU is missing the self-regulation component included in the 1990 Delphi Report. However, there is a high degree of overlap between the other skill sets provided. The communication component of the TTU skill set is easily linked with the explanation skill and sub-skills for the 1990 Delphi Report. TTU explains that a critical thinker should be able to communicate critical

Table 3: *TTU critical thinking skills and sub-skills*

Skill	Sub-skills
Evaluating information	Separate factual information from inferences
	Interpret numerical relationships in graphs
	Understand limitations of correlational data
	Evaluate evidence and identify inappropriate conclusions
Creative Thinking	Identify alternative interpretations for data or observations
	Identify new information that might support or contradict a hypothesis
	Explain how new information can change a problem
Learning and problem solving	Separate relevant and irrelevant information
	Integrate information to solve problems
	Learn and apply new information
	Use mathematical skills to solve real-world problems
Communication	Communicate ideas effectively

analyses and problem solutions effectively while the 1990 Delphi Report describes explanation as stating results, justifying procedures, and presenting an argument (American Philosophical Association, 1990; TTU, 2008).

There is a strong similarity between the interpretation sub-skills provided by the 1990 Delphi report and evaluating information sub-skills described by TTU. The sub-skill categorization for the Delphi Report is further explained as the ability to classify and categorize data provided. This sub-skill aligns to the separating factual information from inference sub-skill described by TTU. Additionally, the Delphi Report describes decoding significance as the ability to interpret significant information given. This sub-

skill shares similarities with the TTU sub-skill of interpreting numerical information in graphs. The TTU sub-skill listed as understanding the limitations of correlational data has common features to the Delphi sub-skill of examining ideas or the ability to identify issues and relationships. Finally, the TTU sub-skill of evaluating evidence and identifying inappropriate conclusions has a connection to the Delphi Report's identifying arguments sub-skill. This sub-skill explains a thinker's ability to determine if information provided supports a given claim (American Philosophical Association, 1990; TTU, 2008).

Although the TTU skills of creative thinking and learning and problem solving do not directly align with a 1990 Delphi skills, the sub-skills described for each of these skill sets do indicate a high degree of consensus. Within the TTU skill of creative thinking, the sub-skill identifying alternative interpretations for data or observations shares many characteristics with the 1990 Delphi sub-skill conjecturing alternatives. Conjecturing alternatives relates to being able to form alternative solutions for problem solving. The Delphi sub-skill of querying evidence describes a thinker's ability to determine what additional information is needed to solve a problem. This sub-skill is similar to the TTU sub-skill requiring the learner to identify new information that might support or contradict a hypothesis. Additionally, the Delphi sub-skill of assessing arguments or evaluating the basis for an argument or conclusion overlaps with the TTU sub-skill of explaining how new information can change a problem (American Philosophical Association, 1990; TTU, 2008).

Finally the TTU skill of learning and problem solving has two sub-skills that closely related to two sub-skills in the Delphi study. The TTU sub-skill of separating

relevant information for irrelevant information falls in line with the Delphi sub-skill of analyzing arguments and the TTU sub-skill of integrating information to solve problems shows similarities to the Delphi sub-skill of drawing conclusions. Analyzing arguments is described in the Delphi report as the ability to identify different conclusions from all the information provided, while drawing conclusions is explained as finding the conclusion best supported by the evidence (American Philosophical Association, 1990; TTU, 2008).

Although the set of sub-skills for the 1990 Delphi Report and the TTU sub-skill set are not identical, there is a large degree of overlap. Table 4 presents the alignments between the critical thinking sub-skills presented by TTU and those described by the 1990 Delphi Report (Tennessee Tech University, 2008; American Philosophical Association, 1990).

Theories Related to Improving Critical Thinking Skills

The components of critical thinking definitions and related skill sets stem from learning theories. In relation to critical thinking, these theories have evolved over time from a focus on dimensions of behaviorism to the cognitive domain and later to include constructivist views. Variations seen between the critical thinking definitions and skill sets parallel the evolution of learning theories.

Evolution of learning theories.

Behavioral theories. Theories related to understanding the way in which individuals learn have evolved from the focus of external or behavioral changes to internal or cognitive changes. Behaviorism, the first psychological perspective to have a significant impact on understanding how humans learn, emerged in the early 1900s. Although there are numerous behavioral theories, some of the overlapping assumptions

Table 4: *TTU and 1990 Delphi Report sub-skills alignment*

TTU	Delphi Report
Separate factual information from inferences	Categorization
Interpret numerical relationships in graphs	Decoding significance
-----	Clarifying meaning
Understand limitations of correlational data	Examining ideas
Evaluate evidence and identify inappropriate conclusions	Identifying arguments
Identify alternative interpretations for data or observations	Conjecturing alternatives
Identify new information that might support or contradict a hypothesis	Querying evidence
-----	Assessing claims
Explain how new information can change a problem	Assessing arguments
Separate relevant and irrelevant information	Analyzing arguments
Integrate information to solve problems	Draw conclusions
Learn and apply new information	-----
Use mathematical skills to solve real-world problems	-----
Communicate ideas effectively	Explanation

of behaviorists include the idea that humans and animals learn in the same way and that learning should be studied by scientific inquiry or more specifically by observing the type of response that occurs as the result of an environmental stimuli. Additionally, many behaviorists agree that internal cognitive processes should be excluded from scientific study because they cannot be observed directly. These theorists also subscribe to the idea that learning involves a behavioral change and that organisms are born with blank slates and acquire behaviors due to environmental experiences. Some

teaching practices that stem from behaviorist theories include emphasis on behavior, drill and practice, methods of breaking habits, and rewarding students for a desired behavior. Critical thinking concepts, such as transfer and problem solving, emerged from behaviorist ideas (Pavlov, 1927; Thorndike, 1911; Watson, 1913; Guthrie, 1935; Hull; 1943; Skinner, 1938) but most current views are centered on cognitive perspectives.

Cognitive theories. Since 1960, the predominant perspective in learning has shifted from behaviorism to cognitivism or cognitive psychology. The focus shifted from observing environmental conditions to explain learning to the evaluation of cognitive processes, how people perceive, interpret, remember, and think about the environmental events that they experience. Some coinciding beliefs of the various cognitive theories include the idea that some learning processes may be unique to human beings, individuals are actively involved in the learning process, and the individual's knowledge, beliefs, attitudes, and emotions are interconnected. Many cognitive theorists also agree that inferences can be drawn from the observation of individual responses to different stimuli to provide information about the person's internal mental events that produced the response. These theorists also subscribe to the idea that learning involves the formation of mental associations that do not necessarily result in a behavioral change and that learning is a process of relating new information to previously learned information (Piaget, 1959; Vygotsky, 1962; Tolman, 1959).

The majority of cognitive theories fall into the category of information processing theory because they focus on how people process information received from the

environment. However, more recently, theorists have observed that people do not just process information directly received from their environment, but instead they construct knowledge from this information. The construction of this knowledge is known as constructivism and constitutes another area of cognitive theories not described by the information processing theory (Collins & Green, 1992; Driver, 1995; Hiebert & Raphael, 1996; Leinhardt, 1994). Constructed knowledge allows learners to develop their own representation of information to facilitate learning (Bossard, Kermarrec, Buche, & Tisseau, 2008).

A third area of cognitive theories includes contextual views. This idea places an emphasis on the immediate environment or context of learning and behavior (Greeno, Collins, & Resnick, 1996; Perkins & Salomon, 1989; Sternberg & Wagner, 1994). Piaget and Vygotsky's Developmental Theories fall into this category. In Piaget's Developmental Theory she described the distinct stages in which cognitive development occurs and suggested that cognitive development results from interactions that children have with both their physical and social environment (Inhelder & Piaget, 1958). Vygotsky's Developmental Theory suggests that children learn most from attempting activities that they cannot yet do from individuals that are more advanced and competent in these skills (Vygotsky, 1962). Contextual views focus on situations where learning and thinking are influenced by the physical and social environments in which the person is immersed. These views can be described by situated learning, situated cognition, and distributed intelligence. Current explanations of the critical thinking concepts of transfer and problem solving are predominantly related to cognitive theories (Ormrod, 1999).

Important critical thinking concepts. Critical thinking is a complex concept that involves both transfer and problem solving while also requiring that the thinker effectively evaluate and interpret data, evaluate ideas and other points of views, demonstrate creativity and resourcefulness in learning, and effectively and persuasively communicate the findings (Quality Enhancement Plan, 2010). Transfer is expressed in the transfer of knowledge or skills; this is a concept where by which you learn something in one situation that affects the way in which you perform or learn in another situation. Problem solving is a form of transfer; this is a concept where by which you transfer knowledge and skills that you previously learned to solve a problem (Ormrod, 1999).

Concept of transfer. Transfer can be described in various ways including positive versus negative, vertical versus lateral, and specific versus general. Positive transfer occurs when learning in one situation facilitates learning in another situation; whereas, negative transfer occurs when learning in one situation hinders learning in another situation. Vertical transfer refers to the ideal of building more complex knowledge from basic skills, while lateral transfer describes the application of a constant level of knowledge from one context to another. Finally, specific and general transfer differ in the idea that specific transfer requires an overlap of knowledge between two tasks as opposed to general transfer where the knowledge between the two tasks is different (Ormrod, 1999).

A number of factors have been linked with the learner's ability to transfer information. These factors include the idea that meaningful learning is more beneficial in promoting transfer than rote learning and that the better the learner understands the

information, the more likely the information can be transferred to a new situation. Additionally, transfer occurs more easily when two situations are similar to one another and general principles are transferred more easily than specific facts. Also, practice with various examples increases the ability to apply information to new situations; however, over time the probability of transfer decreases (Gick & Holyoak, 1987; Ausubel, Novak, & Hanesian, 1978; Perkins & Salomon, 1989).

Concept of problem solving. Problem solving can be divided into two categories of problems, well-defined and ill-defined. In general problems have three components, givens, goals, and operations. A well-defined problem provides the learner with clearly stated givens and goals, all information needed to solve the problem, and an existing algorithm to determine the correct answer. This type of problem usually has one correct solution. An ill-defined problem provides the learner with an ambiguous goal, only partial information needed to solve the problem, and no existing algorithm to use for determining the correct answer. Also, this type of problem typically has several possible solutions as opposed to one correct answer. Due to the lack of straightforward information provided in ill-structured problems and the potential for various answers, these problems are more difficult to solve than well-structured problems and require more complex problem solving strategies (Eysenck & Keane, 1990; Simon, 1978). A number of strategies have been linked with a learner's ability to solve problems, such as allowing the learner to identify the problems themselves, providing information on resources for learners to search for information on solving ill-structured problems, and scaffolding or providing a structure that supports strategies for solving difficult tasks

(Gagne, 1985; Simon, 1978; Schoenfeld, 1992; Mayer, 1987; Sternberg & Frensch, 1993).

These two central concepts of critical thinking, problem solving and transfer, are related. When solving a new problem, the learner often draws upon information used to solve a prior problem with similar parameters. Transfer is necessary in order for the learner to apply the previously learned information to the new situation. Due to the relationship between problem solving and transfer, focusing on improving transfer should serve to improve problem solving as well.

Related theories. Theories related to transfer and problem solving have significantly evolved over time from perspectives of behaviorism to cognitivism and finally to constructivism. General transfer was first introduced through the formal discipline theory in the 1700s. This theory reflected the idea that by exercising the mind through learning, the learner is able to learn more quickly and deal with new situations more effectively. However, early behavioral theorists that followed, such as Thorndike and Woodworth (1901), suggested that transfer only occurs when the original task and transfer task have identical elements or specific transfer. Thorndike's Theory of Identical Elements led to later behaviorist theories that focused on stimulus and response characteristics. Depending on the relationship between the stimulus and response, either positive or negative transfer would transpire; however, these theorists did not believe that general transfer, in its broadest sense, occurred. By redefining the identical elements of Thorndike's Theory as units of declarative and procedural knowledge, Anderson's Adaptive Control of Thought (ACT) Theory began a movement away from behavioral ideas and towards the cognitive. The ACT Theory established that transfer is

dependent on the degree to which qualities are shared between different tasks (Anderson, 1976).

Other cognitive theories such as the Information Processing Perspectives and Contextual Perspectives focused more on the specific context of the material learned (Atkinson & Shiffrin, 1968; Lave, 1988). For instance, in the Information Processing Perspective, the belief is that the learner will only be able to transfer information from learned skills to new skills if it is retrieved at the appropriate time. Retrieval cues must be present to determine what relevant knowledge is brought to the working memory. Information Processing theorists, such as Atkinson and Shiffrin, draw a comparison between cognitive processes and computer processing in that certain steps are required for memory storage and retrieval (Atkinson & Shiffrin, 1968). The Contextual Perspective focuses on the environment and social aspects in which learning is situated. The theory of Situated Learning debates the idea as to whether learning in a specific context can be transferred to new ideas (Lave, 1988), for example, the ability to transfer something learned in a classroom setting to a real world scenario.

More recent theories of transfer of knowledge and skills are based on constructivism. Constructivism is designed to promote an authentic and realistic experience for each learner by encouraging the use of multiple pathways and processes when approaching a problem (Bossard, Kermarrec, Buche, & Tisseau, 2008). Development of constructivism theory is attributed to Piaget and the identification of the states of child development. Piaget proposed that the thinking development of a child does not develop smoothly but instead moves into new areas and obtains new capabilities at certain points. (Piaget, 1969). Bruner (1983) also contributed to

constructivism theory through his belief that learners draw upon current and past knowledge to construct new ideas and concepts. In later years, he expanded his framework to include social and cultural aspects of learning (Burner, 1996). In addition, Ausubel, Novak, and Hanesian (1978) introduced the idea of advanced organizers as a way to form a bridge between new learning material and existing related ideas.

Cognitive Flexibility Theory described. Building on constructivist theories presented by Bruner, Ausubel, and Piaget, the Cognitive Flexibility Theory was later developed by Spiro, Feltovich, and Coulson (1987). This theory was designed to deal with complex and ill-defined or ill-structured problems. This theory focuses on the transfer of knowledge and skills for application in new situations. The idea of cognitive flexibility is to provide the learner the ability to reconstruct knowledge in a variety of ways depending on the demands of a changing situation with a goal of understanding these evolving scenarios (Spiro, VIspoel, & Schmiyz, 1987). Central to this theory is the use of real world contexts to promote transfer of basic knowledge to dynamic situations. The Cognitive Flexibility Theory is also designed to support the use of interactive technology which it draws from the Symbol System Theory developed by Salomon in his efforts to explain the effects of media on learning. Salomon contends that schema are important in how messages are perceived and that effective instruction requires a match between cognitive demands of the task, the skills required by the process, and the skill level of mastery for the learner (Salomon, Perkins, & Globerson, 1991).

Cognitive Flexibility Theory applied. Graddy (2001) acknowledges that the Cognitive Flexibility Theory leads to case-based learning and established a four component structure for learning in this way. The first component includes the

introduction of a variety of case studies to show the multi-dimensional nature of real world scenarios. This collection of case studies is used to help the learner understand the complexity of a particular topic. For the second component, the learner must evaluate the case studies and determine commonalities or themes that can be extracted from the cases. The third component included the development of mini-cases through the breakdown of complete cases into parts. The analysis of these mini-cases can help the learner focus on the overlapping themes and make connections regarding concepts, methodologies, and definitions. Finally perspectives, including concepts and semantic elements, could be addressed within a mini-case. This component incorporates the use of hyperlinks to provide the learner with access to different perspectives of the fundamental knowledge, ideas, and definitions related to the themes (Graddy, 2001). Through this method, the learner takes an ill-structured problem represented with a variety of case studies and breaks down the key components to evaluate overlapping themes. Through the use of hyperlinks, the learner can view other perspectives related to the important ideas and concepts.

In the area of health care, the constructs of the Cognitive Flexibility Theory have been applied to education in medicine (Jonassen, Ambruso, & Olesen, 1992). A variety of clinical cases were presented and medicine students were asked to assess the diagnosis and treatment of details presented in transfusion medicine cases using various information sources. Hyperlinks were included in the material delivery as part of a multimodal delivery design. From this study, the authors concluded that the following four considerations should be taken when applying the Cognitive Flexibility Theory: 1) the activity provides multiple representations of the content, 2) over-simplification of the

instructional material should be avoided and the material should include content dependent knowledge, 3) information is case-based and emphasizes the construction of knowledge as opposed to the transmission of information, and 4) the information includes interconnected knowledge sources and avoids compartmentalization (Jonassen, Ambruso, & Olesen, 1992).

Evaluation of the Cognitive Flexibility Theory in terms of the relationship between views of learning, teaching, and the treatment of subject matter in online instruction suggests a beneficial framework. The Cognitive Flexibility Theory allows for a course structure design that permits learners to move back and forth between various instructional tools to access content from different perspectives. This theory advances learning through the development of flexible representations of knowledge to assist in promoting a meaningful understanding of the material and allow for the use of this knowledge in new situations (Ludwig, 2000).

Additionally, the Cognitive Flexibility Theory provided a useful framework for the University of Wisconsin-Madison's STEP Project Group's work in designing an interactive web-based professional development environment for educators. The goal of this project was to help educators acquire useful scientific knowledge about student learning and development. The Cognitive Flexibility Theory allowed for a flexible design in complex and ill-structured domains where advanced understanding and ability to solve real world scenarios was desired. The approach applied in this project, included defining the learning domain, identification of the domain perspectives, themes, and concepts, cases to illustrate and define the domain, an interface to guide learner-controlled navigation through the web, mapping of multiple paths to link cases and

domain ideas, and a guide to focus the learner and foster reflection. From this project, the authors learned that students prefer multiple paths to reach a concept, that students navigate the site by centering around the case as opposed to proceeding from concept to concept, and that students had to be reminded to use additional information instead of directly referring to the provided inquiry links (Siegel, et al., 2000).

The Cognitive Flexibility Theory was intended to support interactive technology including hypertext and web-based instruction. In linking the application of this theory to web-based instruction, Jacobson (1994) described the most relevant elements as the use of rich case studies and examples, the use of multiple forms of knowledge representation, linkage of abstract concepts to case examples, demonstration of conceptual knowledge, encouragement of knowledge assembly from different conceptual and case sources, the promotion of active learning of complex knowledge at an advanced stage of learning, and enhancement of the ability of students to transfer their knowledge to new situations. In addition, this theory includes a number of constructs related to teaching modalities and cognitive development, such as anchored instruction, situated knowledge, constructivism, adaptivity, multimodality, transfer, knowledge representation, problem-based learning, case-based teaching and learning, analogy, and assessment. This theory ties multimodality, in terms of multimedia, hypermedia, and adaptivity to learning and instruction, to critical thinking enhancement (Honegger, 2007; Siegel, et al, 2000).

Need for Critical Thinking Skills in Health Care

Importance in health care professions. The ability to think critically has been identified as a key mindset for health care professionals (Kenimer, 2002). However, in

addition to clinical laboratory professionals, nurses have indicated inadequate critical thinking abilities in graduates from formal education programs (Brock & Butts, 1998). Although there are many differences between the nursing profession and the clinical laboratory profession, both involve dynamic work environments and require employees to have the ability to think critically and apply knowledge learned in the classroom to new situations. Many parallels with regards to critical thinking can be drawn between nursing education and the education provided in the clinical laboratory programs including the benefit of implementing additional critical thinking exercises in the classroom and the need for transfer of knowledge and integration of concepts between topics (Brock & Butts, 1998; Kenimer, 2002; Greer, 2008).

Importance in clinical laboratory professions. The importance of problem solving skills and the ability to think critically have also been identified as key characteristics of clinical laboratory professions (Beadling & Vossler, 2001; Beck & Doig, 2007; Greer, 2008). In addition, clinical laboratorians need to be independent, flexible, and have a willingness to learn in order to keep up with technological changes, automation, and reductions in personnel seen in today's clinical laboratory (Beadling & Vossler, 2001). The goal of Kenimer's study was to identify and describe critical thinking behaviors important to the clinical laboratory profession by surveying practitioners in the field of CLS (Kenimer, 2002). The survey asked professionals to rank the importance of critical thinking behaviors. Findings of this study indicate that professionals found critical thinking to span all learning domains from cognitive, behavioral, affective, to situated and contextual. Respondents also felt that these skills should be taught within the

context of the field. Overall, the study found strong relationships between behaviors of critical thinking and all aspects of practice (Kenimer, 2002).

A survey conducted by UTMDACC-SHP of employers hiring local and nationwide graduates from medical laboratory science, molecular genetic technology, cytogenetic technology, cytotechnology, and histotechnology pointed to three job requirements that could be enhanced with improved critical thinking skills in entry level technologists, including the ability to verify results and catch mistakes, evaluate significance of findings, and troubleshoot. Employers also felt that better critical thinking skills in entry level technologists would improve laboratory productivity and, thus, lead to better quality of care for patients (Greer, 2008). Finally, the survey found that employer's viewed critical thinking as essential to performing and improving areas of the clinical laboratory, such as improving laboratory techniques or researching new diagnostic tests (Greer, 2008).

Additionally, a study of nationally certified CLS conducted by Beck and Doig (2007) evaluated the relationship between educational preparedness and career expectations for CLS students. These new professionals from across the country identified troubleshooting, resolving problems, and performing multiple tasks as areas in which more preparation was needed. The authors also reported that although entry level laboratory professionals felt well prepared for their jobs, they also indicated that improvement in the teaching of some tasks could serve to better prepare graduates for the work environment. Additionally, these professionals will need to have improved critical thinking skills to keep up with the increasing need to monitor performance

parameters, classify and track errors, and determine the necessity of laboratory testing to better direct patient care (Beadling & Vossler, 2001).

Link between clinical laboratory education and accreditation. The majority of entry level professions enter the workforce after graduating from an accredited program. Medical laboratory science, molecular genetic technology, cytogenetic technology, and histotechnology programs are accredited by the National Accrediting Agency for Clinical Laboratory Sciences (NAACLS), while cytotechnology programs are accredited by the Commission on Accreditation for Clinical Laboratory Programs (CAAHEP). All accredited clinical laboratory programs must design their curriculum to meet the accrediting agency standards. The NAACLS or CAAHEP focus predominately on curriculum content that must be delivered to each student and place no explicit requirement or strategy for enhancing critical thinking skills (NAACLS website, 2008; CAAHEP website, 2009) Few studies have assessed the critical thinking skills gained through the educational programs and skill set required for entry level clinical professionals.

In addition to program accreditation standards, the higher-degree institutions offering these programs are also accredited by a regional accrediting body, such as the Southern Association of Colleges and Schools (SACS). This accreditation body is now requiring all member institutions to design an action plan to enhance student learning. A number of institutions, including UTMDACC-SHP, have chosen to focus this Quality Enhancement Plan (QEP) on improving critical thinking skills in their student population. In a focus group held at the University of Texas M.D. Anderson Cancer Center (UTMDACC), employers consistently mentioned the need for the improvement of critical

thinking skills in clinical laboratory students. This group of employers pointed to the following two areas as places in which improved critical thinking was necessary: 1) interpreting results and 2) coping with equipment breakdowns. These employers also expressed concern of a disconnect between student learning and the real world (Greer, 2008).

Level of critical thinking in educational programs. Although it has been recognized that there is a need to improve critical thinking in this student population, the question of how to do this has not been fully addressed. Furthermore, many allied health educators do not have a clear understanding of these principles or how to implement them (Zygmunt and Schaefer, 2006). A study at Temple University was conducted to assess the critical thinking skills of nursing faculty. This survey found that most faculty members had received no educational training on critical thinking. Two critical thinking assessment tests were given, the California Critical Thinking Skills Test (CCTST) and the Learning Environment Preferences (LEP) to evaluate the level of critical thinking skills in nursing faculty. The CCTST found considerable variation in faculty members' ability to think critically, and the LEP found that faculty had not reached the intellectual level needed to think critically (Zygmunt & Schaefer, 2006). No formal study has been published using the measures to evaluate the ability of clinical laboratory faculty to address aspects of critical thinking.

Although most educators identify critical thinking as an important part of the educational process, few can give a clear explanation of what critical thinking is and even fewer actually incorporate it into the classroom setting (Paul & Elder, 2008). Again, this has not been evaluated in the realm of clinical laboratory education; however, this

conclusion was reached for teacher preparation programs. In a survey conducted by the Commission of Teacher Credentialing to evaluate teacher preparation programs, it was found that though 89% of those surveyed found critical thinking to be a primary objective of their education, only 19% could give a clear explanation of critical thinking and as few as 9% clearly incorporated into their curriculum on a typical day (Paul & Elder, 2008). It is essential that educators have the ability to understand and teach critical thinking skills in order to produce students with these skills. In a focus group at UTMDACC-SHP, faculty acknowledged concerns regarding their own knowledge of critical thinking skills and methods of implementation (Greer, 2008). Other limitations discussed regarding the implementation of critical thinking into the clinical laboratory curriculum included time limitations for curriculum development, implementation, and faculty training (Greer, 2008).

Developing Methods for Enhancing Critical Thinking Skills

Definition of theoretical constructs. A number of constructs related to the Cognitive Flexibility Theory including constructivism, transfer, anchored instruction, situated knowledge, problem-based learning, case-based learning, multimodality, adaptive learning, knowledge representation, analysis, and assessment have been incorporated into educational curricula (Siegel, et al, 2000). Many of these constructs have been used to directly target the enhancement of critical thinking skills. In addition to constructivism and transfer described earlier, the theoretical constructs associated with the Cognitive Flexibility Theory are interrelated in a number of ways.

For instance, anchored instruction is a paradigm for technology-based instruction and has similarities to situated knowledge and case-based and problem-based learning.

Anchored instruction involves designing activities around an “anchor” that situates a problem or issue to be evaluated by the student within a case or scenario that is of interest to the student. The instructional materials include resources that allow the students to explore as they attempt to problem solve. Bradford and Stein (1993) created an “anchor” in the form of an interactive video. In one situation, the video was an adventure that required students to apply mathematics to solve the problem. Similarly, situated knowledge focuses on the idea that knowledge needs to be presented in an authentic context and that learning needs to involve social interactions and collaborations (Lave & Wenger, 1991). Therefore, case studies provide a beneficial structure for enhancing situated knowledge and delivering anchored instruction.

Problem-based learning is another construct of the Cognitive Flexibility Theory; it is both a teaching process and an approach to curriculum. As a teaching process, it replicates the commonly used systematic approach to resolving problems or meeting challenges that are encountered in life and career. As an approach to curriculum, it consists of carefully selected and designed problems that demand the learner to acquire critical knowledge, problem solving skills, self-directed learning strategies, and team participation skills (Barrows & Kelson, 1995). In problem-based learning classrooms, students are typically asked to create solutions to real-world problems that are often complicated with few clear-cut answers (Colburn, 2003). With problem-based learning, the student is typically engaged in an active learning environment facilitated by the instructor. Although most contexts include student discussions and social interactions, not all definitions directly specify this type of interaction. Problem-based learning has been described as learning that results from the process of working towards the

understanding of a resolution to the problem, where the problem is encountered first in the learning process (Barrows & Tamblyn, 1980). Two essential features of problem-based learning have been listed as the initial trigger, the learning that students undertake while researching the issues identified, and the use of knowledge to further understand the trigger situation in later applications (Lloyd-Jones, Margetson, & Bligh, 1998).

Problem-based learning and case-based learning are both methods of inquiry-based learning. However, as problem-based learning promotes open inquiry, case-based learning promotes guided inquiry (Srinivasan et al, 2007). In case-based teaching and learning the student is able to develop skills such as analytical thinking and reflective judgment by reading and discussing complex, real-life scenarios. Providing instruction with a case-based approach exposes students to subject matter knowledge through the study and analysis of cases involving real-world problems (Siegel et al, 2000). In a study comparing case-based learning to problem-based learning, first, second, and third year medical school courses at the University of California, Los Angeles and the University of California, Davis were switched from a problem-based learning format to case-based learning. Ten months after the curriculum change, students and faculty having undergone both methods completed a questionnaire to evaluate their perception. Findings indicated that case-based learning was preferred because it provided fewer unfocussed tangents, less busywork, and more opportunity for clinical skills applications (Srinivasan et al, 2007).

An additional construct related to the Cognitive Flexibility Theory is multimodality. This construct may be beneficial in the delivery and construction of course content, such

as webpages. A text has been defined as being multimodal when it contains at least two semiotic systems, such as linguistic, visual, audio, gestural, and special (Anstey & Bull, 2010). These authors listed webpages as an example of this type of text because they have the ability to combine a variety of elements such as sound effects, oral language, written language, music, and still or moving images (Anstey & Bull, 2010). Because online information can be provided in a multimodal format, it has the ability to accommodate different learning styles (Burgess, 2001).

Likewise, adaptive learning uses computers as interactive teaching devices, whereby the presentation of educational material is adapted according to the knowledge level of the learner. Alternative learning systems strive to transform the learner from a passive receptor of information to a collaborator in the educational process (Paramythis & Loidl-Reisinger, 2004). Adaptive learning has been defined as a learning environment that monitors the activities of its users, interprets these activities on the basis of domain-specific modules, infers user requirements, and acts upon available knowledge of its users and the subject matter to dynamically facilitate the learning process (Paramythis & Loidl-Reisinger, 2004).

Additionally, computer technology is embedded in the knowledge representation construct, as it applies theories and technologies from logic, ontology, and computation (Sowa, 2000). This construct is useful in the development of online educational platforms for content delivery as it involves designing computer systems to perform tasks typically requiring human intelligence. This construct directs the conversion of real world knowledge into a computerized form (Sowa, 2000). By engaging students in instruction and assessment that involve only a single form of knowledge representation,

their understanding of the subject matter they are learning is constrained (Jonassen & Carr, 2000). Mindtools are computer software applications, such as databases, spreadsheets, and hypermedia tools that employ knowledge construction for which learners can learn with, not from. The use of these tools facilitates interpretation, organization, and design of knowledge on the part of the learner (Jonassen & Carr, 2000).

Analogies, another construct related to the Cognitive Flexibility Theory, build bridges between familiar and unfamiliar concepts. Analogical thinking maps concepts across experiences and domains to help understand unfamiliar concepts (Dirks, 1998). Additionally, analytical reasoning is used to understand and make decisions about an unknown situation or phenomenon by exploring parallels with other experiences (Dirk, 1998). Studying and creating analogies have been shown to help students develop comprehensive vocabularies and concepts as they improve reasoning ability and critical thinking skills.

Additionally, incomplete analogies are commonly used in assessment through standardized testing because correct completion of these elements has been considered evidence of higher level thinking (Nessel & Graham, 2006). This example of direct assessment is a common method used to directly evaluate what students know or can do by comparison to a measurable learning outcome. Indirect assessments can also be used to measure the perceived extent or value of a learning experience. These assessment tools are typically not as strong due to assumptions that may be included in this type of assessment (Rogers, 2006). There are a number of methods of assessment

including both direct and indirect methods that will be discussed later in the literature section.

Use of theoretical constructs in education.

Case-based and problem-based learning strategies. Of the constructs related to the Cognitive Flexibility Theory, problem-based learning and case-based learning, along with multimodality have been incorporated into health professions and allied health professions programs for many years, beginning with problem-based learning in medicine as early as the 1960s. One study in the area of clinical laboratory science, focused on the inclusion of problem-based learning into a clinical correlations course curriculum. The goal of the course was not only to improve critical thinking skills but to integrate concepts across disciplines (Beadling & Vossler, 2001). In this study, challenging case studies were presented and discussed by the students in small groups. Portions of the case were released to the students over a three to five week period to allow them to progress through the information. During this time, the students analyzed the data and recorded significant information. At the conclusion, they presented their findings both written and orally and were graded with defined rubrics. The study findings indicate that the problem-based courses can improve the student's ability to evaluate information from various disciplines in order to solve problems in both the laboratory and didactic curriculum, as well, improved communication and presentation skills (Beadling & Vossler, 2001).

To evaluate the use of case-based learning in nursing education, a study was conducted to evaluate the level of critical thinking skills for students completing a case-based learning course versus those completing a didactic course covering the same

information. Using the CCTST, students participating in the case-based course were found to have increased critical thinking skills at the completion of the course, as compared to those participating in the didactic course (Kaddoura, 2011).

A case-based virtual information system is being constructed at the University of Texas Health Science Center at San Antonio, as part of the institutions Quality Enhancement Plan, with a goal of improving student learning through use of a case-based virtual health care education resource. The research contains a bank of case studies and can be delivered to individual students, small groups of students, or as part of an instructional activity in an interactive, multimedia approach. The resource can be adapted to didactic courses, clinical rotations, or a primary case-based to increase case-based learning in existing or new learning activities (Chiang, 2008).

The University of Wisconsin has implemented the use of, what they describe as case-based problem-based learning into their semester long educational psychology course to aid in improving critical thinking skills in their student population (Siegel, et al, 2000). For this project, case-based learning was utilized to allow the student to learn subject matter knowledge through the analysis of a series of cases. The problem-based learning aspect allowed for the acquisition of knowledge through student centered discussions pertaining to the analysis of the case studies. Stemming from the Cognitive Flexibility Theory, the case-based problem-based learning, also incorporated web-based instruction. Students enrolling in the course were divided into groups of five to seven and presented with case studies in a web-based format. The case study material was multimodal, included readings, videos, and inquiry materials. In addition, a problem scenario related to the case scenario was provided. The students were asked to solve

the problem related to the case study, using provided information, along with other electronic resources. In addition to providing the case in a web-based format, student resources for accessing information through hyperlinks and multimedia were also provided to assist with addressing the problem presented. Students were surveyed regarding the course and references provided. Most were satisfied but suggestions were made to include better instructions and to supply additional resources. Changes were made to improve the course and expand to a distance delivery version (Siegel, et al, 2000).

The manner in which problem-based and case-based learning are incorporated and used by educational programs appears to vary from complete curriculum to single course, or only targeted assignments within a course or curriculum. In order to better understand the extent that problem-based learning is used within clinical laboratory educational programs, a survey was delivered to clinical laboratory science directors across the country. Findings of this study indicated that 60% of respondents described having implemented a problem-based learning methodology into their curriculum (Warning, 2004). However, the degree to which this methodology is incorporated may vary drastically from institution to institution. Similarly, a review of the use of case-based learning in health professions programs and allied health programs indicated that although students responded positively when questioned about the enhancement of their learning through case-based learning, the degree to which this pedagogy was incorporated varied greatly. Some curricula were found to incorporate a single case, while others designed an entire year's curriculum using this format. Class sizes ranged

from 50 to over 1000 students and group sizes ranged from no groups to greater than 30 students per group (Thistlethwaite, et al., 2012).

Additional strategies. Published articles were not found to specifically evaluate the effectiveness of adaptive learning and knowledge representation in the education of health care professionals. However, the American Society for Clinical Pathology Board of Certification delivers its certification examinations through computer-based adaptive testing; whereby, the level of questioning presented to the test taker is adjusted based on the number of correct answers chosen (American Society for Clinical Pathology, 2012). The exam is structured in a multiple choice format and provides a scaled score at the completion of the exam, allowing for the more difficult questions to be weighted with greater point values than the simpler questions. In this way, the clinical laboratory test taker is not taught, but assessed through an adaptive application. Although analogies can be used in teaching and assessment, no published study was found to specifically evaluate the use of the construct for improving critical thinking in the education of health care professionals.

Implementing Methods for Enhancing Critical Thinking Skills

Methods of implementing theoretical constructs into curriculum. Although face to face interactions with students are most commonly used for instruction and enhancement of critical thinking abilities, time and distance do not always allow for this option (Lunney, Frederickson, Spark, & McDuffie, 2008). Currently, many undergraduate programs are delivered in an online format. The comparison between a face-to-face and online format has shown to have no significant difference in the success of the learners (Clark, 2002; Phye, 1997). However, the majority of these

studies have compared course grades for each format as opposed to a critical thinking assessment instruments to directly evaluate the difference in gain of critical thinking skills for face-to-face and online instruction. One study of adult learners in a liberal arts course found no significant difference in pre-test / post-test CCTST scores for students completing a face-to-face course and those completing the online version (Derwin, 2009). However, the content of these courses was not directly focused on increasing this skill set for the enrolled students.

The majority of publications surrounding critical thinking in online education discuss the difference between synchronous and asynchronous student discussions (Chang, 2002; Yang, Newby, & Bill, 2005). The asynchronous discussions allow the students to take advantage of the online setting by working at their own pace. A qualitative study designed to evaluate critical thinking for graduate students in online courses employing asynchronous discussion boards through observation and survey found that online learning can enhance critical thinking (Chang, 2002). Another study of undergraduate distance learning students found that the inclusion of Socratic dialogs in asynchronous discussion boards improved critical thinking in the participating students as observed by quality of discussion (Yang, Newby, & Bill, 2005). Not only is the online format amenable to self-pacing by the learner but it also allows the material to be displayed through various mediums to accommodate different learning styles (Burgess, 2001).

It has been noted that online education has influenced trends away from teacher-centered pedagogy and towards constructivism, student-centered pedagogy (Burgess, 2001; Knowlton, Knowlton, & Davis, 2000). Although many models of online learning

include a social aspect, in addition to cognitive and teaching components (Kajder & Bull, 2004; Wang, 2005; Garrison & Anderson, 2003), writing online reflections without interaction with other students managed to remain helpful for student critical thinking development (Wang, Woo, & Zhao, 2009). No studies were found that directly compared the inclusion of student discussion in online courses to those lacking this component. However, it has been suggested that higher order learning can be developed through computer-based environments with appropriate teacher presence, relating to design, facilitation, and assessment (Garrison, Anderson, & Archer, 2000). Furthermore, online courses stress self-directed learning, whereby the learner is required to take primary responsibility for planning, implementing, and evaluating their own learning process.

Instruction and teaching have been described separately with instruction including animate or inanimate events and teaching the process of arranging such events (Gagne, Briggs, & Wager, 1992). The way in which the events are arranged can influence the success of a given course. Although student satisfaction in online courses has shown to be significantly influenced by the clarity of the design, interaction with the instructor, and participation in discussions with other students (Swan, 2001), computer responses can be adapted to contribute to verbal immediacy (LaRose & Whitten, 2000). By formatting the responses provided by a computer to stimulate immediacy, the student feels closer to the instructor even without the direct instructor response. Additionally, structuring the response and questioning in a way that maximized the instruction through teaching and adequately injecting Socratic questions to guide thought process might advance critical thinking through online instruction. Furthermore,

Elder (2007) characterizes critical thinking as self-guided, self-disciplined, self-directed, self-disciplined, self-motivated, and self-corrective thinking.

Implementation strategies for clinical laboratory education. Lunney et al, (2008) provided 10 strategies to facilitate critical thinking in health science students through online education and reported positive outcomes as the result of implementing these strategies into their online health science curriculum. The strategies included: asking questions that required information seeking; providing expectations for students to respond in their own words, motivating students through grading criteria, stimulating students to include examples of concepts and theories, providing case studies applicable to course content, prompting students to ask questions of each other and instructors, phrasing questions to require additional research or reading, promoting student debates on discipline specific controversial topics, requiring students to use journaling, and reinforcing student use of critical thinking skills (Lunney, Frederickson, Spark, & McDuffie, 2008).

Critical thinking is reinforced by providing a learning environment that is conducive to exploration of the unknown, truth-seeking, open-mindedness, logical reasoning, and flexibility. This type of environment can be created through praise and reinforcement (Lunney, Frederickson, Spark, & McDuffie, 2008). The 10 strategies were formed to enhance reasoning, judgment and decision making, and problem solving for students in relation to specific domain content once basic content knowledge has been achieved. Students were graded on their participation in online discussion boards and the amount of credit received was based on the quality of each posting (Lunney, Frederickson, Spark, & McDuffie, 2008).

Assessing Methods for Enhancing Critical Thinking Skills

Methods of assessing theoretical constructs. There are a variety of methods for assessing student outcomes. Rogers (2009) categorized methods of assessments into two groups, direct measures and indirect measures. Both direct and/or indirect measures have been used to assess student outcomes upon implementing critical thinking strategies in a curriculum. Direct measures provide the direct examination or observation of student knowledge or skills against measureable performance criteria; whereas, indirect measures determine the opinion or self-report of the extent or value of learning experiences (Rogers, 2009). Depending on the desired target for measurement, direct, indirect, or a combination of measurement tools may serve useful. Surveys, questionnaires, interviews, archival records, and focus groups can serve as indirect measures while standardized exams, portfolios, simulations, performance appraisals, and behavioral observations typically serve as direct measures (Rogers, 2009). Although there are few publications regarding the assessment of critical thinking in clinical laboratory educational programs, other aspects of allied health use a variety of assessment methods, with direct assessment in the form of standardized testing instruments appearing most frequently in publications.

Critical thinking assessment tests.

California critical thinking assessments. The California Critical Thinking Disposition Instrument (CCTDI) and the California Critical Thinking Skills Test (CCTST) are two commonly used critical thinking standardized testing instruments (Phillips, Chesnut, & Rospond, 2004). Both assessment instruments were developed based on the critical thinking consensus definition established by the 1990 Delphi Report. The

CCTDI, offered by Insight Assessment, was designed to measure the dispositional aspects of critical thinking. This instrument is composed of 75 statements expressing beliefs, values, attitudes, and intentions that relate to reflective formation of reasoned judgment (Insight Assessment, 2011). The test taker has the option of choosing agree or disagree to each of statements. Based on the responses given, a score is provided for seven scales including, truth-seeking, open-mindedness, analyticity, systematicity, critical thinking self-confidence, inquisitiveness, and maturity. Overall, a higher score positively correlates with a strong desire to apply critical thinking skills in decision making and problem solving (Insight Assessment, 2011).

The CCTST is offered by the same company as the CCTDI. According to the Insight Assessment website, the CCTST is the gold standard of critical thinking tests and has been proven to predict strength in critical thinking authentic problem situations and success on professional licensure examinations (Insight Assessment, 2011). This instrument provides a measure of critical thinking skills focusing on the cognitive domain and evaluates areas of analysis and interpretation, inference, evaluation and explanation, inductive reasoning, deductive reasoning, and total critical thinking score. Although the content of this assessment does not center on allied health topics, it continues to be offered to assess health science students and professionals in a variety of professions such as nursing, occupational therapy, physical therapy, pharmacy, and dentistry (Rogal & Young, 2008; Velde, Wittman, & Voss, 2006; Bartlett & Cox, 2002; Allen & Bond, 2001; Williams, et al., 2006). Few studies have been performed to evaluate the ability of this test to accurately measure critical thinking skills necessary to the health care professions.

The CCTDI was developed through discovery sessions and focus groups of college level critical thinking educators. From these initial discussions, 150 items were piloted to evaluate their relevance to understanding an individual's disposition toward critical thinking. Through the pilot study, any items that failed to adequately discriminate among test takers were eliminated, along with items where the response inversely correlated with the test takers overall score and items that added little or no additional value to the overall score. Upon completion of this evaluation, 75 items were selected for the final version of the test (Facione, Facione, & Giancarlo, 2000). The CCTST was validated in a similar way; members of the test's target population were asked to interpret or understand the items on the exam. Additionally, items that were found to negatively correlate with overall CCTST scores were eliminated (Facione, Facione, & Giancarlo, 2000). Factor analysis was used to determine the subsections for each of the tests.

After development of these assessment instruments, the correlation between CCTDI and CCTST outcomes was observed. Findings indicate that although the correlation between total scores for these exams was significant ($p < 0.001$) in entry and exit level nursing students, it is weak with an r value of 0.201 and 0.169 respectively (Facione, 1997). These findings fail to explain 97% of the difference observed between the students' disposition toward critical thinking and their critical thinking skills, evaluated at the same time point. Based on these findings, the authors concluded that the variation in critical thinking skills is not potentially associated or attributed to variation in overall disposition towards critical thinking (Facione, Facione, & Giancarlo, 2000). Additionally, no specific disposition of the CCTDI was found to strongly correlate

with any single skill for the CCTST (Facione, Facione, & Giancarlo, 2000). Based on results for the CCTDI and CCTST conducted for physical therapy students, no descriptive characteristics were found to correlate with CCTDI score change; however, age was found to be negatively associated with score change for the CCTST (Bartlett & Cox, 2002).

To further evaluate these assessment instruments, the scores were correlated with scores of existing, validated measures of the same constructs, such as the GRE and Watson-Glaser Critical Thinking Appraisal (WGCTA). A significant correlation ($p < 0.001$) was observed for the CCTST and total GRE score for graduate nursing students having an r value of 0.719. This assessment instrument has also been reported to correlate highly with both the GRE verbal and analytical sections (Facione, Facione, & Giancarlo, 2000). The correlation observed between the CCTST and WGCTA was stronger when evaluated for nurses entering and exiting an educational program. At entry the correlation had an r value of 0.405 and at exit an r value of 0.544 (Facione, Facione, & Giancarlo, 2000). These significant findings suggest that the GRE and CCTST measure similar constructs, as well as the WGCTA and CCTST. Although significant ($p < 0.001$), a weak correlation was observed for college GPA values in a validation study of the CCTST with an r value of 0.200 (Facione, Facione, & Giancarlo, 2000).

Health Science Reasoning Test. In addition to the CCTDI and CCTST instruments, the Health Science Reasoning Test (HSRT) is also offered by Insight Assessments. Like the CCTST, the instrument was developed to target the cognitive aspects of the 1990 Delphi Report's consensus critical thinking definition. However, this

test was specifically developed for health science and health care professional preparation programs. Although students are not required to have knowledge of health care, the exam is framed around health care setting scenarios (Insight Assessment, 2011). This test has been applied in fields such as medical, dental, nursing, and physical therapy to assess the ability of modified educational curriculums to improve critical thinking skills in health care students. The reliability and validity values for this test are not published by Insight Assessment. However, the American Dental Education Association reports the internal validity of this assessment tool to range from 0.77 to 0.83 and a moderate reliability for the analysis and inference subsections (American Dental Education Association, 2012).

Additionally, one study tested the construct validity of the HSRT by evaluating the tests ability to distinguish novice and expert physical therapists. When evaluating the total score for the exam, the experts scored significantly higher than the novice professionals evaluated (Huhn, Black, Jensen, & Deutsch, 2011). Another study evaluated critical thinking abilities in relation to descriptive and demographic predictors for undergraduate nursing students in Australia using the HSRT (Hunter, et al., 2014). This study found no relationship between age or gender and the total HSRT score. However, the authors did report year of education and nationality to significantly predict HSRT score. The average HSRT score increased with each year of nursing education (Hunger, et al., 2014).

Watson-Glaser Critical Thinking Appraisal. Another critical thinking exam, the Watson-Glaser Critical Thinking Appraisal (WGCTA), is available in formats with varying numbers of questions; however, each is designed to assess five critical thinking skills,

including, inference, recognition of assumptions, deductions, interpretation, and evaluation of argument (Watson & Glaser, 1980). Like the Insight Assessment tests, the WGCTA has been used in a variety of health care professions to evaluate both professionals and students. As described above, this instrument was significantly correlated with the CCTST, indicating that the two instruments measure similar constructs (Facione, Facione, & Giancarlo, 2000). The test-test reliability has been reported at 0.81 (Watson & Glaser, 1994).

Validation of WGCTA was attempted by measuring internal consistency and comparing the instrument to other student outcomes. The WGCTA was evaluated in terms of internal consistency for students majoring in psychology, educational psychology, and special education. The overall findings for this group produced an r-value of 0.92. The correlation between the WGCTA scores and course grades for this same group was low at $r=0.30$ but statistically significant ($p<0.05$) (Watson & Glaser, 1994). A more recent study conducted to evaluate the relationship between critical thinking ability and nursing competence in clinical nurses found that the WGCTA correlated highly with nursing competence measured with the Nursing Competence Scale (Chang, Chang, Kuo, Yang, & Chou, 2011). However, a study conducted with first year pharmacy students to predict student academic performance found that the WGCTA was unable to predict success in these students better than GPA and PCAT scores (Lobb et al, 2006).

Critical Thinking Assessment Test. Tennessee Tech University (TTU) developed the Critical Thinking Assessment Test (CAT) (Stein, Redding, Ennis, & Cecil, 2007) to evaluate critical thinking skills across all disciplines. In addition to its own

faculty members, preeminent theoreticians and educators in the area of learning science were invited to evaluate and help refine the instrument to ensure it was based on principles of learning and cognition. This test was designed to assess four major critical thinking skills, including effective evaluation and interpretation of data, application of existing knowledge to solve problems in new situations, creativity in learning and problem solving, and effective and persuasive communication (TTU, 2008). However, unlike the Insight instruments, the CAT only yields one total score and does not provide information about abilities for individual skills.

A pilot study was conducted with faculty and students from various institutions across the country to evaluate reliability and validity of this assessment tool. Faculty determined that all 12 sub-skills included on the CAT were valid for improving critical thinking. The sub-skill with the lowest agreement was using mathematical skills to solve complex real-world problems, at 79%. This same group of faculty also evaluated the validity of each test question and found the face validity to be high; the question with the lowest agreement was at 81% (Stein, et al., 2007). After evaluating the results for undergraduate students, the internal consistency of the tool was found to be 0.695. The CAT had significant ($p < 0.01$) correlations with the CCTST, SAT, and student GPA (Stein, et al., 2007). The correlation with the CCTST was 0.645, suggesting that the two exams are able to measure similar constructs. The SAT correlation was found to be 0.527 while the correlation with student GPA was slightly lower at 0.345 (Stein et al., 2007). The scoring reliability between graders for this study was found to be 0.82. The authors also report after preliminary analysis that gender, ethnic background, and racial group are not predictors of CAT score (Stein et al., 2007).

Because of the newness of this test, no uses were found in the area of healthcare and health sciences. However, the CAT has been used in science courses to assess critical thinking skill sets. A multi-discipline education course designed to improve critical thinking and science literacy at Sam Houston State University was able to observe significant differences between students completing a modified curriculum and those completing the standard curriculum (M. Rowe, personal communication, July 20, 2011). In addition, after utilizing the test in a nature of science and inquiry course at the University of Wisconsin-Madison, the instructor described the CAT as fair and able to evaluate relevant critical thinking abilities (B. Tikoff, personal communication, July 20, 2011).

Comparison of assessment instruments. The critical thinking assessment tools described above are only a subset of those available; however, not all critical thinking is assessed with a direct measure. Critical thinking skills are also commonly evaluated using performance appraisals, rating forms, rubrics, and portfolios (Rogers, 1996). Although the CAT provides a quantitative total value, it is one of the few instruments that provide a score for the cognitive skill set using an essay format. The CCTST, HSRT, and WGCTA all use a multiple choice format to assess the cognitive critical thinking skills of test takers, while the CCTDI allows the test taker to agree or disagree with disposition statements related to critical thinking. Of these critical thinking assessment tests, HSRT is the only option that is designed specifically for health science and health care professional preparation programs. Research on psychological and educational testing indicates that a well-developed multiple choice test can measure higher order cognitive skills in a valid and reliable manner (Haldyna, 1994).

Literature Gaps

Although there is no consensus on the definition of critical thinking in the literature, there are many similarities between the definitions and skills outlined regarding these concepts. The working definition put forward by UTMDACC-SHP outlines four clear skills to address for producing a critical thinker, including effective evaluation and interpretation of data, application of existing knowledge to solve problems in new situations, demonstration of creative and resourcefulness in learning and problem solving, and effective and persuasive communication (Quality Enhancement Plan, 2010). These skills are based on four main areas outlined in the CAT exam designed by Stein et al (2007). Through this literature review, this skill set has been aligned with skills from other studies such as the 1990 Delphi Study (American Philosophical Association, 1990), which was used in the development of the CCTST and CCTDI, along with the HSRT (Insight Assessment, 2011). Although not published, links between the UTMDACC-SHP skills defined and HSRT skills assessed have been drawn. Although limited, published information does exist relating to the validity of the HSRT, thus suggesting that the skills represented on the assessment tool are likely measuring critical thinking skills. However no publications have been found to assess the use of the four skills identified in the UTMDACC-SHP definition for development of a model for improving critical thinking curriculum. This study aims to fill this gap by designing a model to include modules that target each of these aspects of critical thinking.

Some constructs from the Cognitive Flexibility Theory, such as problem-based learning, case-based learning, multimodality, transfer, and constructivism have been

included in health professions and allied health education; however, the number of publications in relation to clinical laboratory education is limited. Additionally, these studies within the allied health professions did not incorporate these constructs in a way that focused on the principles of the Cognitive Flexibility Theory (Jonassen, Ambruso, & Olesen, 1992). Although studies were conducted that included interactive, web-based content delivery, none were found to deliver all course content in this manner.

Asynchronous discussions were found to be just as successful as synchronous discussions in online courses; however, no publications were found in the literature to evaluate the ability to enhance critical thinking skills without a social aspect. Methods such as Socratic questioning and scaffolding have been successfully applied to synchronous and asynchronous online discussions; however, this study aims to implement a model to include these strategies in independent critical thinking modules. In order to facilitate the creation of an independent and flexible entry-level clinical laboratorian (Beadling & Vossler, 2001), this study aims to employ principles and constructs of the Cognitive Flexibility Theory in the development of a web-based, interactive model and to evaluate the ability to improve critical thinking skills through independent learning.

Methods of assessing critical thinking, such as the CCTST and CCTDI have been widely used in for assessment of both allied health professionals and educational curriculums to determine levels of critical thinking skills for test takers. Assessment tools such as the CAT and HSRT are newer; therefore, fewer publications exist regarding their use in this field. The HSRT was chosen for this study due to its development for use with health care and health science professional programs. An assessment

instrument, such as the HSRT, designed to measure the cognitive skill set developed by the 1990 Delphi study delivered in a pre-test / post-test format, should produce a valid and reliable representation of the participating students' gain in critical thinking abilities. Although the HSRT has not been used as extensively as the CCTST for assessing the critical thinking cognitive skill set, it is similar in format and design. The CCTST has been used routinely for delivery in a pre-test / post-test format.

Summary

The literature indicates that the clinical laboratory profession is changing at an unprecedented rate, and graduates entering this profession are challenged to increase the scope of practice by playing a more active role in the health care team (Beadley & Vossler, 2001). In order for clinical laboratory graduates from formal programs to succeed as entry level technologists, they need the proper tools to facilitate critical thinking and transfer of knowledge from the educational setting to real world scenarios. Critical thinking is necessary for these entry level professionals to handle essential skills, such as troubleshooting, resolving problems, and performing multiple tasks (Greer, 2008). However, the method for addressing and assessing these skills is not outlined by the accrediting bodies. The literature does not present a current method for filling this gap. No publications were found to improve all cognitive components of critical thinking in this population of students. Studies have shown a disconnect between educators' interest in implementing critical thinking skills into their curriculum and their ability to do so (Zygmunt & Schaefer, 2006).

In addition, faculty members have cited lack of time as an obstacle to targeted enhancement of this critical thinking skill set (Greer, 2008). Outside of the classroom,

time is needed for faculty development and course design of activities specifically targeting these skills. While within the classroom, time is required for implementation and assessment of this skill set (Greer, 2008). However, in order to meet the specific accreditation requirements for each program, little time is left for creation and delivery of additional content. This study aimed to design a model to enhance critical thinking skills that once developed, could be implemented into the curriculum with web-based platform capabilities. Although this study allocated class time for implementation, the model has the ability to be implemented in a course or to be delivered in a distance manner. Additionally, it contains all elements of instruction, along with a rubric for grading each module and, therefore, will not require faculty development of critical thinking skills and methods for enhancement. Based on current gaps that exist in the literature, this project was developed to design, implement, and assess a model to enhance critical thinking in clinical laboratory students.

Chapter Three - Methods

Introduction

This project aimed to improve critical thinking skills in clinical laboratory students through the design and implementation of a web-based model. The study assessed the ability of the developed model to improve critical thinking skills in this student population at the University of Texas M.D. Anderson Cancer Center (UTMDACC). Constructs related to the Cognitive Flexibility Theory were used in the design and implementation of this model. Prior to beginning this study, the project was approved by the Institutional Review Boards at Virginia Commonwealth University (IRB # HM 15303) and the UTMDACC (IRB # PA13-0475).

This chapter discusses the design of this experimental project, while explaining the type of research, rationale, and appropriateness of this study. In addition, details of the population and sample are included, with specific emphasis placed on sample type, size, location of participants, and sampling procedures. The intervention created for this study is described in detail, paying specific attention to the model structure, intervention design, and implementation. The instrument used to assess the outcome of this study is described in terms of appropriateness for the study and instrument validity and reliability, followed by an in depth explanation of the administration and scoring of the instrument. Data collection and analysis is also included in this chapter.

Research Design

This study involves the design, implementation, and assessment of a critical thinking model. It utilized a one-group pre-test / post-test quasi-experimental design.

The study design is depicted as follows:

Study Design: $O_1 \quad X \quad O_2$

O_1 denotes the first observation period; and O_2 denotes the second observation period, with X indicating the intervention placement.

The first observation period was a pre-test delivered to all students enrolled in the Critical Thinking in Health Professions course at the University of Texas M.D. Anderson Cancer Center's School of Health Professions (UTMDACC-SHP). The second observation period was a post-test delivered to the same group of students. An electronic version of the Health Science Reason Test (HSRT) was used for both the pre-test and post-test. The critical thinking model served as the intervention for the study. The model was designed prior to the first observation period and implemented immediately following the pre-test. It was completed just prior to the second observation period. The post-test was given after model completion and at the conclusion of the course. Participants were enrolled in the study after design completion and before the pre-test and model implementation. Although all students enrolled in the course completed the observations and interventions, only scores for those meeting study inclusion criteria and consenting to participation were included in the statistical analysis.

The Critical Thinking in Health Professions course was offered to junior level students in clinical laboratory technology programs at UTMDACC-SHP during the 2013 fall semester. There are five programs at UTMDACC-SHP included under the heading

of clinical laboratory technology programs, including medical laboratory scientists, molecular genetic technologists, cytogenetic technologists, cytotechnologists and histotechnologists. The junior year for clinical laboratory students at UTMDACC-SHP is composed of students from all five disciplines. Each program has a set of required courses and additional elective courses. For the molecular genetic technology, and cytogenetic, and medical laboratory science programs, this course was required for all junior students. For the histotechnology program and cytotechnology program, this course was considered an elective in which junior students have the option of enrolling.

Upon enrollment in the course, students were provided with general course information, such as a syllabus, research study goals and guidelines, and the consent document for review. Announcements and video links were also provided to further describe the course goals, format, content, grading, and communication modalities. On the first day of class the research assistant for this study reviewed the study information and consent form with the students. She then provided them with a random, unique numerical identifier. She kept documentation linking this information with the student name but did not provide it to the PI in order to keep her blinded to consenting students and to reduce bias. Students used their unique numerical identifiers for the completed demographic form and the pre-test and post-test. The demographic form and consent forms were collected on the first day of class by the research assistant. The students also completed the first observation at this time.

The implementation and assessment portion of this study were designed to be completed over a 14-week period, using a pre-test / post-test format. The first observation or critical thinking assessment pre-test took place during week 1 of the fall

semester. This observation served as a baseline measurement of the students' critical thinking abilities. Over the next 12-weeks, the students received the intervention or critical thinking model. This model comprised all content for the Critical Thinking in Health Professions course, including reference documents and assessments. During the final week of the fall semester, the second observation or critical thinking assessment post-test took place. The observations on week 1 and week 14 were conducted in a face-to-face manner and the intervention was delivered online. Although the HSRT was electronic, students were asked to be present on week 1 to review the study information and collect consent forms. The observations were offered in the classroom to provide consistency between location and time of day. During this fall semester all participating students also completed program-specific course work demanded by their program curriculum.

Quasi-experimental studies are susceptible to threats to internal validity. Utilization of a pre-test / post-test format can minimize certain threats but increase others. Common threats to this design type are history, maturation, mortality, testing, instrumentation, and statistical regression. These threats were considered in the development of this study and the strategies used for design, implementation, and assessment of the critical thinking model were chosen to minimize as many as threats as possible. However, it is not possible eliminate extraneous variables such as outside experiences and influences, student fatigue, attitude toward course and topic, and regression due to testing error. Additionally, the use of a convenient sample from a single institution may introduce threats to the external validity of the study, such as interactions between the group and intervention and interactions between the setting

and intervention. External validity threats can limit the generalizability of the study findings.

Population and Sample

Participant criteria. The target population for this study included all junior students enrolled in a clinical laboratory program at UTMDACC-SHP. For the 2013-2014 school year, UTMDACC-SHP aimed to enroll a total of 60 junior level students into the five clinical laboratory programs, including 15 juniors into the medical laboratory science program, 20 juniors into the molecular genetic technology program, 15 juniors into the cytogenetic technology program, four juniors into the cytotechnology program and six juniors into the histotechnology. These enrollment goals for this school year were similar to those from previous years. Participants in this study were then required to enroll in the Critical Thinking in Health Professions course offered at UTMDACC-SHP during the fall semester. The MGT, MLS, and CGT programs required this course as part of their program curriculum and the HTL and CT programs offered it as an elective. Inclusion criteria were enrollment in a clinical laboratory program at the UTMDACC-SHP and enrollment in the Critical Thinking in Health Professions course, along with student consent to participate, completion of the observations, completion of course, and a minimum age of 18 required by the Institutional Review Board.

The number of participants was dependent upon the number of junior level students enrolled by the programs and course enrollment. Of those enrolled in the course, only those consenting to participate were included in the study. Also, any students not at the junior level or below the minimum age of 18 were eliminated from the study. Students were not eliminated for failing to complete all portions of the module

but were eliminated if they withdrew from the course during the semester or did not complete both the pre-test and post-test assessments. However, missing module assessment data was tracked. Because the critical thinking model was incorporated into a semester course, all students enrolled in the course completed the observations and interventions. Data from students not included in the study was removed by the study research assistant prior to statistical analysis. The PI was also the course instructor and remained blinded to the consent status of each student and also the HSRT scores. Random, numeric identifiers were used to blind her and all information linking the students to the identifiers was kept secure by the research assistant. The research assistant also served as the contact for students regarding study participation. Students were allowed to withdraw from the study at any time during the semester. Participation in the study and HSRT scores had no bearing on the student grade. All grades were determined by participation via answer form submission and rubric point analysis.

Statistical evaluation. The pre-test was used to measure the level of critical thinking skills students had upon entry into the study. The post-test was used to measure this level after completion of the study intervention. The difference between the pre-test score and post-test score was evaluated to determine whether this score increased or decreased over 12-week period. A two-sided, paired t-test was used to evaluate the null hypothesis proposed for this study, there is no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. An alpha of 0.05 was used to determine whether this change was significant, and the power was set at 0.80, producing a 0.20 beta requirement. The HSRT includes 33 multiple choice questions

and is scored with one point per question, giving a total possible score of 33 for each assessment.

Previous studies employing the HSRT as a critical thinking assessment instrument presented statistically significant results with an average pre-test / post-test differences of 1.5 points and approximately 3.5 standard deviations per group (Huhn, Black, Jensen, & Deutsch 2011; Sullivan-Mann, Perron, & Fellner, 2009). Achieving this mean difference and standard deviation for this study would allow for a statistically significant result with a sample size of 43 students (Dawson & Trapp, 2004). Additionally, these values would produce an effect size of 4.3, describing a medium effect (Cohen, 1988). A target enrollment of 60 juniors in all clinical laboratory programs would allow for the ability to produce significant results with up to 28% below target. This overage would allow for low enrollment or loss of students due to non-consent or non-completion of the course or observations.

In addition to the HSRT pre-test and post-test score evaluation, participant demographic information was analyzed along with faculty design evaluations and student course evaluations. Module completion and Sakai usage were also monitored. The rubric scores generated for each module and sub-skill were assessed, along with HSRT pre-test and post-test numerical sub-topic scores and HSRT categorical interpretations of critical thinking abilities generated by the testing agency. The change in time spent on each HSRT assessment was also monitored. To further interrogate the data, regression models were analyzed to evaluate the relationship between HSRT change values and demographic and usage characteristics for study participants.

Intervention

The intervention for this study was a multimodal critical thinking model developed to improve critical thinking in clinical laboratory students. The model was designed to include four components, each aimed at increasing a different aspect of critical thinking outlined by the critical thinking definition adopted for this project. These include effectively evaluating and interpreting data, applying existing knowledge to new situations, creative and resourcefulness of learning, and effectively and persuasively communicating. The format and delivery of the modules are derived from constructs related to the Cognitive Flexibility Theory, including constructivism, case-based learning and teaching, and web-based instruction. These activities were used to develop a web-based critical thinking module that could be implemented and assessed in a clinical laboratory curriculum. Appendix A includes a diagram of the overall model design, Appendix B depicts the design format, and Appendix C outlines the detailed content for each module included in the model.

Model design. The first aim of this project was to design a multimodal critical thinking model to enhance critical thinking in clinical laboratory technology students. To address this aim, the model or intervention had to be developed. The content for the critical thinking model was organized into an introduction and four modules. The introduction section presented the concept of critical thinking to the students and provided background information for the fourth part of the critical thinking definition, communicating ideas effectively. Each of the first three modules was directed at improving one of the additional three aspects of the critical thinking definition adopted for this project. These three modules were each subdivided into three parts. The three

parts within a module targeted the same set of critical thinking sub-skills but served a different purpose.

Module 1 was directed at effectively evaluating and interpreting data. The first part of this module introduced four related sub-skills including, separating factual information from references, interpreting numerical relationships in graphics, understanding the limitations of correlational data, and identifying inappropriate conclusions. The second part of this module integrated these four sub-skills and the third evaluated the students' ability to utilize these sub-skills, along with effective communication. Module 2 targeted the application of existing knowledge to solve problems in new situations by introducing three sub-skills in the first part. The sub-skills related to this topic are identifying and evaluating evidence for a theory, identifying new information that might support or contradict a hypothesis, and explain how new information can change a problem. The second part of this module required students to use all three sub-skills and the third part assessed their use of these sub-skills, as well as communication. The third module was aimed at improving the third part of the critical thinking definition, creativity in learning and problem solving. This skill had four related sub-skills, separating relevant from irrelevant information, integrating information to solve problems, learning and applying new information, and using mathematical skills to solve real-world problems. Part II of this model allowed students to practice integrating these sub-skills and part III evaluated their ability to do so. Again, communication was also evaluated in part III. Module 4 was used to incorporate all sub-skills introduced in the model. The diagram in Appendix A provides a visual of the model design.

Module format. The modules were formatted in Sakai, an online learning platform. Students can be enrolled into a created course, restricting access to only those permitted. There are various options for organizing content within this system. Additionally, this system accommodates a wide variety of file types and links. For this model, instructions for completing the model were provided in a section within the syllabus section of Sakai. That section was renamed “Course Information”. The announcement section was used to deliver additional instructions. The reference information was organized in folders within the resources section, retitled “References”. The assessments were created and organized in the test and quizzes section that was retitled “Assessments”. This system also provided a calendar for students showing all assessment due dates and any class meetings. Additionally, it provided an option for emailing fellow students or the instructor, a discussion board, and a chat room. The students were also able to view their current grade within the system and the instructor could enter each assessment and alter the grade or add necessary comments and personalized feedback.

Adaptive release. The model was designed within this system using an adaptive release option, to present students with only a portion of the information at a time. After completion of the initial observation or pre-test, students were provided with access to the reference material for the introduction section and their assessment answer forms. Upon submission of the reference answer form, the student received the reference material for the subsequent section. The adaptive release was set to open the next set of reference material every time the preceding assessment showed a non-zero score in the gradebook. Every assessment included a dummy question asking students if they

had reviewed the associated reference material and a “yes” or “no” multiple choice answer option. An answer of “yes” provided an assigned point value, resulting in a non-zero score for the gradebook. This was necessary because all other questions requested short answer responses and required manual instructor scoring. When students submitted each assessment, they were also provided with a comment reminding them to proceed to the next section.

Scaffolding. The model contained an introduction section and four modules. Each of the first three modules was divided into three parts and the fourth module served as a summation of all skills previously introduced. The model content was formatted using scaffolding to allow students to build on their knowledge base. The first part of each module was meant to introduce a specific sub-skill designed to achieve an aspect of critical thinking targeted by the module. The corresponding assessment was viewed as practice, and a complete response was awarded full credit. Students received automatic feedback that would appear for each question upon submission. The feedback was not personalized but multiple possible responses were provided. The students were also reminded to review the feedback and that it was not all inclusive of correct answers. They were given the opportunity to ask for more specific feedback from the instructor regarding their specific response.

The second part of each module required the students to incorporate all related sub-skills within each module to evaluate a short case study. This integration of skills was also viewed as practice and students submitted response and received feedback just as they did for the first part. For the third part of each module, students were again asked to integrate each sub-skill for the module in evaluation of a full case study.

However, for this part, each short answer response was graded using a rubric and the feedback was not accessible until after the due date had passed. For this third part of each module, each written response was also evaluated for effective communication. By designing the modules using three parts, the students are first introduced to the sub-skills and allowed to practice integrating them in the evaluation of a scenario before being evaluated on the skill set. Students were allowed to progress through the model regardless of performance. The fourth module did not include any new information but instead required students to evaluate a case study and related problem scenarios using all sub-skills introduced in the previous modules. This scaffolding approach was used to enhance the transfer of knowledge and support the incorporation of strategies for problem solving.

Anchored instruction. The content of each module was formatted to improve critical thinking while presenting the information around a topic of interest to the students. Each student in the study was enrolled in a clinical laboratory program; therefore, the case studies and problem scenarios were anchored around these disciplines. One specific topic, lung cancer, was chosen as the focus. The single topic was used because it involves multiple clinical laboratory disciplines in the diagnosis and treatment process. Also, a single topic was chosen to prevent the amount of new background information required for each module. The goal of anchoring the learning activities around a topic of interest was to increase interest and better hold the attention of the participating students. The first module focused on the epidemiological nature of lung cancer and associated risk factors. The second centered around laboratory testing

related to diagnosis and the third included information on treatment options and targeted therapies.

Case-based learning. Each module incorporated case-based learning. The first part of each module only contained a short scenario but the second part included a short case study and the third included a full case study. The use of this learning style allowed the material to be presented to students in a realistic format by including information that might be encountered in a real-world setting. This format allowed for the presentation of subject matter content in a manner that retained the complexity of the situation. Case-based learning also promoted guided inquiry while stimulating analytical thinking and reflective judgment. This construct is closely linked with anchored instruction and use of these two constructs in the model allowed for the presentation of case studies anchored around the clinical laboratory disciplines.

Multimodality. Multimodality was used to deliver the reference material. Content was presented using various formats to accommodate different learning styles. Each module contained references in a variety of different formats. Videos were used along with PowerPoints, websites, peer reviewed publications, and links to databases. Students were able to click on each link to access the content and independently interact and navigate through the material. Although the adaptive release only allowed them access to the new material as they completed the previous assessments, the previous reference material remained accessible to them throughout their work on the entire model. They were encouraged to go back and review any previous links or assessments they needed as they progressed through the model.

Asynchronous modality. The model was delivered in an asynchronous format, allowing students to proceed through the content at varied rates. Due to the adaptive release, they could move ahead at their own pace. However, in order to ensure that all students completed the model in the required time period due dates were set. Students were required to submit each assessment by a given date. They were provided at least one week between assessment due dates. Various communication modalities were also provided to the students to allow them the opportunity to discuss course content with their classmates and the course instructor. A classroom was made available each week for face-to-face discussions amongst students, as well as online options. Asynchronous discussion boards, chat rooms, and email access were provided to students to allow them the option of interacting with each other. Although content discussions were allowed, and even encouraged, independent responses to assessment questions were required. Use of the online resources was monitored but not required. The classroom usage was neither monitored nor required. The asynchronous nature of the course provided students the freedom to work with the content at their own pace and at a time that best suited their schedule. Appendix B depicts the model format.

Module content. The model was designed to allow the students to begin with an introduction section. This section contained reference material focusing on defining critical thinking and the importance of this skill set. It also included reference information describing methods of effective communication, with an emphasis on the written form. Upon evaluation of the reference material students completed an assessment related to these topics. They were asked to define critical thinking in their own words, to list three important skills for a critical thinking to have, and to explain how those skills might help

them personally and professionally. They were also asked to complete a short questionnaire evaluating their communication skills and to evaluate a written statement for errors in communication.

Effectively evaluate and interpret data. The content in module 1 was directed at improving the first part of the critical thinking definition, ability to effectively evaluate and interpret data, while also evaluating the students written communication skills. The module 1, part I, sub-skill 1 reference section contained a document defining terms and concepts and a presentation, both related to the first sub-skill targeted by this module, separating factual information from inferences. After reviewing this material students completed an assessment that contained a short scenario with a table containing information about the association between lung cancer patients and follow-up default status. The students were asked to identify a list of statements as fact or inference and to describe any associated assumptions.

Like the reference material in module 1, part I, sub-skill 1, the reference material for module 1, part I, sub-skills 2, 3, and 4 included a list of terms and concepts, along with a presentation targeting each sub-skill. A related assessment was also provided for each sub-skill. For module 1, part I, sub-skill 2, interpreting numerical relationships in graphics, the assessment included a short scenario with a graph depicting mortality rates by race and gender in the United States. Students were asked to interpret the information presented in the graph and to evaluate each of their statements as a fact or inference, while identifying any assumptions.

For module 1, part I, sub-skill 3, the material focused on understanding the limitations of correlational data. The assessment provided students with a short

scenario and a graph representing lung cancer incidence by race and gender. Students were asked to explain what the graph indicated in regards to lung cancer rate in males over time. They were also asked about the level of support that the graph provided for their statement, other possible explanations, and additional variables that might contribute to the observed change.

The ability to identify inappropriate conclusions was the focus of sub-skill 4 in module 1, part I. This assessment included a short scenario with statements describing a correlation between exercise and lung cancer incidence. Questions challenged students to evaluate support for a given hypothesis with explanation, evaluate assumptions, and determine any additional information needed to fully evaluate the scenario.

The content in module 1, part II was intended to assist students in utilization of the four sub-skills introduced in module 1, part I. The reference material provided links to websites, videos, and peer-reviewed publications included to provide students with background information on lung cancer risk factors and prediction models. The assessment included a short case study and table of risk factors related to the case. Students were asked to identify facts and inferences, evaluate related assumptions, explain variable relationships presented in the table, and determine other influential factors. They were also asked to evaluate lung cancer risk over time, identify other contributing factors, determine the appropriateness of conclusions presented, and propose additional potential explanations for the data presented.

The reference material for module 1, part III provided links to a number of journal articles describing HIV and lung cancer. The articles provided various views on HIV as a

risk factor and its associated outcome involving lung cancer. Websites and video links were included to provide additional background information. The assessment for this part was based on a published study on the association between HIV infection and the risk for developing lung cancer. Assessment questions pertained to all sub-skills presented in module 1, part I and integrated in module 1, part II.

Apply existing knowledge to solve problems in new situations. Module 2 content focused on providing students with the ability to apply existing knowledge to solve problems in new situations, as well as and evaluation of their written communication skills. Module 2, part I, sub-skill 1 was directed at identifying and evaluating evidence for a theory and provided students with an explanation of related terms and concepts, as well as a presentation explaining this skill set. The related assessment contained a stated theory and a concept map depicting the connection between lung cancer types and sub-types. Students were asked to use the concept map to find evidence to support the stated theory and to investigate any assumptions in their supporting statements. They were also asked to determine how well the theory was supported.

Module 2, part I, sub-skill 2 provided content related to identifying new information to support or contradict a hypothesis. Related terms and concepts and a presentation were included in the reference section. The assessment provided students with a short problem scenario and reference protocol related to troubleshooting in the laboratory. The students were asked to identify a hypothesis and to determine information needed to evaluate it. They were also required to explain how the information generated could help solve the problem.

For module 2, part I, sub-skill 3, the terms and concepts and presentation were included to explain how new information can change a problem. For this assessment, the students were provided with a short scenario containing test results, additional information related to the scenario, test guidelines, and new findings. They were then asked to determine whether the new information would alter the patient diagnosis and to explain how. They were also asked to identify additional information needed to make their decision and to explain how it would be useful in the decision making process.

The reference material for module 2 included links to websites containing cellular classifications and targeted mutation testing. It also included a link to immunohistochemically stained images and a publication explaining the diagnosis of non-small cell lung cancer (NSCLC). The assessment included a short case study about a patient diagnosed with NSCLC and additional supporting documents included a NSCLC immunohistochemical algorithm, a lung cancer diagnosis and prediction flow chart, and a concept map displaying clinical laboratory disciplines and related testing for NSCLC. The assessment targeted all sub-skills associated with module 2. Questions included in this assessment asked students to use diagnostic information provided to support a stated theory and to justify their response. It also asked them to propose a hypothesis to identify testing errors and to suggest a method to evaluate their proposed hypothesis. They were then asked if the new test information could change the original diagnosis while explain how and why based on the information included with the assessment.

The reference material for part III of this module provided students with a background of lung cancer diagnosis and testing. Links were included to publications on

diagnosis of lung cancer in small biopsies and cytology, guidelines for molecular pathology testing, fluorescent in-situ hybridization evaluation, and a comparison of immunomarkers in NSCLC biopsies. The related assessment targeted all sub-skills introduced in module 2, part I and integrated in module 2, part II. A published case study on a patient with a lung adenocarcinoma was presented and students were told to refer back to images found in the reference articles. Questions were similar to those included in the assessment for module 2, part II.

Creativity in learning and problem solving. The content included in module 3 was used to support creativity in learning and problem solving. The first part of this module used documents to introduce new terms and concepts, along with a presentation explaining each new skill set. The module 3, part I, sub-skill 1 focused on teaching students how to separate relevant information from irrelevant information. The assessment for this sub-skill presented students with a short scenario and extra information about a treatment plan for a lung cancer patient. The students were then asked to identify the most useful information and to explain their selection.

The second sub-skill in the module provided information related to integrating information to solve problems. This assessment included a short scenario and a flow chart defining a treatment plan. Students were required to select additional information to assist in solving the problem and to justify their selection.

The third sub-skill included content aimed at assisting the students with learning and applying new information. This assessment included a short scenario with conflicting information and challenged the students to determine how the new

information should be used to evaluate the situation presented. They were asked to support their response.

The fourth and final new sub-skill contained information on using mathematical skills to solve real-world problems related to situations in a clinical laboratory. The assessment included a short problem scenario requiring students to determine how much of a reagent was required to produce the accurate amount and to justify their answer.

The content for module 3, part II focused on all of the sub-skills presented in module 3, part I. The reference material for this part provided students with background information on NSCLC targeted therapies and related laboratory tests. Video links provided information on molecular tumor testing and lung cancer targeted therapies. Websites and publication links were included to offer additional references on testing and targeted therapies. The associated assessment presented a short case study on treatment options for NSCLC patients and included additional links to a molecular algorithm for molecular testing, a NSCLC mutation overlap diagram, clinical trial information, and mutations related to smoking history. Students were asked to choose tests that provided the most information in the decision making process and to support their choice based on the information provided. They were required to integrate reference information with new information provided to evaluate a diagnosis, to explain how the new information could change their decision, and to evaluate mathematical information presented. Students were required to solve a dosage problem using mathematical skills.

Module 3, part III was directed at assessing the students' ability to integrate all sub-skills introduced in module 3, part I and applied in module 3, part II. The reference material included provided students with links to online databases describing various mutations associated with NSCLC and targeted therapies. Links to articles describing personalized medicine and multiplex testing methodologies for NSCLC were also included. The related assessment provided students with a published case study of a man displaying back pain and a mass in his lung. Additional documents were attached for use with the assessment, including diagnostic strategies for unknown primary tumor identification, algorithms for mutational analysis, mutations by smoking history, mutational overlap diagram for NCSLC, a list of mutational variants and those responding to therapeutics. The assessment questions for this part were similar to those included in module 3, part II. The students were again challenged to integrate all sub-skills introduced in the first part of this module.

Incorporation of all skills presented. Module 4 was included as way of integrating all sub-skills presented in module 1, 2, and 3. No new skills were introduced for this model and no new reference information was introduced. This module contained an assessment with a published case study and a number of additional attachments to be used in applying the critical thinking skills for analyzing the material presented in the case study. The case study described an 18-year old boy with primary lung cancer. The attachments included a graph depicting cancer deaths in Japan, immunohistochemical staining results by site, diagnostic strategies for identifying unknown primary cancers, proposed testing algorithms, mutational overlap in NSCLC, mutations by smoking history, immunomarker results, lung cancer concept map, testing reference ranges, lung

cancer signs and symptoms, serum cancer antigen marker values, and diagram showing causes of lung cancer in non-smokers. The assessment for this module included questions similar to those used in the earlier modules. Questions were included to challenge students to utilize the sub-skills introduced and practiced in this model. A complete outline of all reference and assessment content can be viewed in Appendix C.

Determining module validity. Prior to implementation, the validity of the model was assessed by faculty and adjunct faculty members at UTMDACC-SHP. One professional was chosen from each of the five clinical laboratory technology programs included in this study, MLS, MGT, CG, CT, and HTL. These individuals were given access to the Sakai site containing the complete critical thinking model. The five faculty members were asked to complete a questionnaire related to the evaluation of the critical thinking model and related content. The goal of the evaluation was to assess overall face validity, content validity, and construct validity of the model. Participating faculty members were provided with background information on the project and scoring criteria. A 5-point Likert scoring system was used to rank each topic; a five corresponded to very good, a four was good, a three was given for fair, a two for poor, and a one for very poor. Free space was provided in each section for additional comments.

In order to evaluate the content validity of the mode, the evaluation included questions asked faculty members to review the content and rank the degree to which provided reference material and the associated assessment addressed the sub-skills for each module. Three questions, each with multiple parts, were related to this subject. Each question targeted a different portion of the module. For each part, the associated

sub-skills were assessed. Faculty members were also asked to evaluate the construct validity but ranking the degree to which each module and related assessment addressed critical thinking. The definition of critical thinking adopted for this study was provided to faculty members in the background information section of the evaluation document. Additionally, evaluators were asked to review the face validity and to rank the overall model design, topic chosen, amount of reference information provided, level of reference material provided, level of assessment, ease of use and navigation, platform chosen, delivery method, instructor presence, and usefulness of feedback provided. The faculty evaluation form is included in Appendix D.

Faculty members were given two weeks to review the model and complete the evaluation document. Each document was returned to the PI for analysis and review. Any missing responses were noted and ratings and comments were reviewed by the PI. The scores were summed for each part of each question and divided by the number of responses received. All comments were categorized by sub-skill topic and module association. Prior to implementation the model was adjusted in order to respond to areas with low ratings and specific comments provided.

Development of module evaluation. A student evaluation form was developed by the PI prior to implementation of the critical thinking model. The goal of this document was to collect data from the students in relation to the model organization, content, and topic, model delivery method, and their opinion on each module's ability to address the corresponding sub-skill. The evaluation form included a total of 10 questions. The first four questions required only a single response and provided students with four options to select from in order to best reflect their view of the course

organization with modules and parts, online delivery style, concepts addressed, and topic of lung cancer. Their answer choices were excellent, okay, questionable, and poor. Another question provided students with these same answer choices related to the degree that they felt each objective or sub-skill was met. However, they were asked to select one of the optional responses for each sub-skill. The following question asked students to rate the usefulness of the reference material included with each module and part as very useful, somewhat useful, or not really useful. The next three questions were open-ended and asked students to comment on what they liked most and least about the class, and what changes could be made to improve the course. The final evaluation question asked students if they found the course beneficial and provided them with options of yes, somewhat, or no. Appendix E includes the student evaluation.

The evaluation form was developed and delivered through SurveyMonkey®. Upon completion of the final observation for the study, the post-test, students were provided with a link to the evaluation. An announcement was added to Sakai and emailed to students describing the evaluation and providing a link to access it. The post-test was delivered one week prior to conclusion of the fall semester. No requirements were made for evaluation completion. Additionally, no deadline was set and no additional reminders were set regarding evaluation submission. Upon conclusion of the study, the PI evaluated all received evaluations, noting any missing data, totaling responses per answer choice, and categorizing all free responses.

Demographic questionnaire. A demographic questionnaire was created for use in collecting information from each study participant. The form provided an area at the top for students to enter their unique participant number and brief instructions regarding

participation and data usage. The students were given options to choose from regarding program of enrollment, primary language of English, comfort level with English, level of past education, level of work experience, ethnicity, and gender. They were provided free answer spaces to self-report their student identification number, GPA, and age.

Students that failed to submit a completed form were not removed from the study; however, any missing data was not able to be used in the demographic analysis. The demographic form was included in Appendix F.

Model implementation. The second aim of this project was to implement the multimodal critical thinking model into clinical laboratory technology students' curriculum. To address this aim, the completed model was implemented in a junior year course offered to clinical laboratory technology students at UTMDACC-SHP. The Critical Thinking in Health Professions course was offered to HLT and CT students, and required for MLS, MGT, and CGT students. The course was created for delivery of this model and no other content was included. It was offered as a two-hour, hybrid course. The entire model was delivered over a 14-week period during the fall semester of the 2013-2014 academic year. The course was developed to be implemented in an on-line manner; however, two face-to-face sessions were included for delivery of the pre-test and post-test assessment. All other content was delivered online. A two-hour time was blocked out for each face-to-face session and the same classroom was utilized for consistency with testing. This classroom was also made available to students throughout the semester but no additional face-to-face meetings were required or attended by the instructor. Students were also provided with access to online communication modalities, such as discussion boards, chat rooms, and email.

Although the students were allowed to work ahead, at least one assessment was due each week, with the exception a two week allowance for the assessment related to the final cumulative module. The online nature of the course, allowed students the ability to work at their own pace. They could spend as much or little time with the material as needed. Sakai offers the ability to monitor access and usage. These statistics were evaluated by the PI in terms of visits, activity, and resources utilized by each student. Visits were defined as the activity of entering or visiting a site. The number reflected by the system only represented the initial entry into the site and did not count multiple visits from an individual user while logged into Sakai. Activity was defined as the events generated by tool actions. The specific activity of interest could be selected from a preference menu and tracked for each user over a specified period of time. Resources were described as any action related to a file or folder in the resource section. For this course, the resources section was renamed references; and therefore, this value provided information on a student's access to the reference information.

The Sakai statistics were evaluated by the PI at the conclusion of the course. No minimum requirements were set for student usage and access. However, if a student did not submit an assessment by the deadline, they did not receive credit. Students that failed to complete all submissions were not removed from the study but the missing scores were unavailable for rubric analysis. Students were provided automatic feedback with each submission and encouraged to review it before proceeding to the next section. The feedback review process was conducted in an asynchronous, independent manner and this activity was not enforced or monitored by the PI. Written and video communication was implemented into the modules by the PI to create instructor

presence. Students were encouraged to continue working through the modules and reminded of the focus of the model.

Module delivery. The course began on September 9, 2013 with a face-to-face session scheduled from 1:00-3:00pm in the junior classroom at UTMDACC-SHP. At this time, the PI and research assistant for the study were both present to begin the session. Prior to this session, students were enrolled in the course on Sakai and provided information related to the study and course. The course information section within Sakai included a description of the study and a copy of the consent form for review. Along with a copy of the course syllabus, a video describing what students could expect from the course, and information about the HSRT assessment. Additionally, an announcement was posted providing students with information on what to expect for the face-to-face session. This information was made available to students one week before the first face-to-face session.

First observation. During this first session, the PI reviewed the study information and consent document with the students and then left the room to allow the research assistant to provide random identifiers for the students. She also collected consent forms and demographic questionnaire documents at that time. Once this information had been collected, the PI reentered the room and administered the pre-test. Students entered their random identifiers into the online testing system and began the HSRT assessment. The test allowed 50 minutes for completion and students were allowed to leave the classroom upon submission.

Intervention. At 3:00 pm on that same day, the introduction reference material was set to open and allowed students access to the content. Additionally, at that time

the assessment answer forms because available to all enrolled students. Due to adaptive release options, the students could begin working through the content at their own pace from this point forward. However, to prevent them from getting behind, the due date was set for the introduction assessment answer form at 11:59 pm of the following week. This allowed the students up to one week for review of the reference content and submission of the assessment. Once the due date passed, students could no longer work on the assessment and assessments that had not already been submitted were automatically submitted by the system at this time. However, students did have the ability to reopen the submitted document to review their responses and instructor feedback.

Upon submission of the introduction assessment, the students gained access to the reference material for module 1, part I, sub-skill 1. They were provided a maximum of one week to progress through all four sub-skills related to module 1 and to submit the associated assessments. Students were required to complete the assessments in order and only gained access to the following sub-skill reference material when the previous assessment had been submitted. The due date for these four assessments was set for 11:59 pm. Following completion of module 1, part I, students gained access to module 1, part II. Again, they had up to one week to review the reference material and submit the related assessment. The third part of this module followed in the same way. If a student failed to submit an assessment, the adaptive release would not open the next reference folder for them. The PI had to manually open the folders in those situations to allow the students to progress. However, no minimum score was set to prevent the students' progress through the model.

Once the final portion of module 1 was completed, students moved on to module 2. This module also had three parts. The first part included three sub-skills and like module 1, all three assessments were due a week following the previous submission. The students had to progress through each one in order to receive reference information for the next. The second and third parts followed just as in module 1. The third module was structured in the same way as the first two but included four sub-skills with four related assessments. Upon submission of the module 3, part III assessment, the students were able to move on to module 4. No additional reference material was provided for this section. Because this was a cumulative module, targeting sub-skills from all other modules, the students were given two weeks to complete the assessment. The full implementation schedule is included in Appendix G.

Second observation. The week after the final submission was due, December 9, the second face-to-face session was held again in the junior classroom at UTMDACC-SHP from 1:00-3:00 pm. At this time, the PI and the research assistant for the study were present to administer the post-test to the students. As with the pre-test, the students took an online version of the HSRT and entered the same unique identifier provided to them during the pre-test. The research assistant was present to provide this number to any students that did not remember it from when it was issued. The students were again allowed 50 minutes to complete the assessment and allowed to leave upon submission. At this time, they were notified of the student evaluation and where to find the link in order to access and complete it. The model and course were completed on this date.

Module feedback. The students were provided feedback for each assessment. Sakai allows the instructor to determine how and when feedback is delivered. During model design, all assessment questions were entered into Sakai, along with possible responses for each question in the feedback section. All acceptable responses were not entered, only examples of possible answers. Because this is a critical thinking course and assessments were completed using a short answer format, there was no single correct answer. Students were reminded that they could email the instructor for clarification regarding their specific response at any time during the semester. For the first and second part of each module, the feedback was set to be released to the students immediately upon submission. However, because the third part of each module was evaluated for a grade, the feedback was not set for release until after the due date had passed. The part III feedback was released at 12:01am on the day following the submission deadline.

Students were allowed to view the feedback at any time during the semester and were encouraged to review part I feedback before continuing on to part II and part II feedback before continuing on to part III, as part I and II were meant to be used as practice for part III. The students were reminded to review all feedback before attempting the final, cumulative module 4. In addition to programming in feedback for each assessment, the PI also added comments within the assessment to thank students for their submissions and to remind them to continue moving through the material and to direct them towards the next set of reference material to be released. Additionally, videos were included in each part II and III, as well as in module 4 to remind students to focus on the sub-skills introduced for that section. The additional

comments and videos by the PI were included to assist with instructor presence as the students progressed through the online model.

Model assessment. The third aim of this project was to assess the ability of the multimodal critical thinking model to improving the critical thinking skills in clinical laboratory technology students. The null hypothesis for this study, there is no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum, was connected with this third aim. The primary assessment for this study, the HSRT, was administered in a pre-test / post-test format to evaluate the change in critical thinking skill level for students having completed the critical thinking model. This assessment was designed to evaluate the overall critical thinking ability and to provide information about the change in this skill set for the population studied. The overall HSRT numerical scores were used to assess the study hypothesis. Additional data was gained from the five HSRT sub-topic scores (induction, deduction, analysis, inference, and evaluation), and categorical interpretations of critical thinking abilities (superior, strong, moderate and not manifested) generated by the testing agency.

Model rubrics were used to grade assessments submitted for each module. The rubrics were used to evaluate the ability of each student to grasp the concepts included for each component of a module. These tools did not measure improvement as they were only assessed in a post-test format. In addition, the rubrics did not have the ability to evaluate the students skill set in its entirety but instead evaluated success for each individual module and sub-skill.

The rubrics were designed by a faculty member at UTMDACC-SHP for use with evaluating this same critical thinking skill set and in association with the institution's Quality Enhancement Plan. The rubrics were previously utilized at this institution for purposes of grading a research methods course offered to clinical laboratory junior students. However, no statistical values regarding validity and reliability were generated. The rubrics were included in Appendix H. Demographic information from participating students was also assessed for this study to ensure that the sample was representative and to determine if any of the demographic characteristics had a relationship with model success.

Use of rubrics. Student assessments submitted for the final part of each module and module 4 were evaluated with the rubrics. Once the due date for submission had passed, the PI applied the appropriate rubric to each assessment question. She evaluated the quality of the response and assigned a score. The rubric scores were adjusted to point values for grading purposes. Each complete assessment was worth 100 points and total points per question were divided up equally and adjusted based on rubric scores. Tables below show the number of questions per module assessment, point values related to each question and point values related to each sub-skill, respectively. A separate rubric was used to assess each sub-skill. Once the grading was complete, students were able to view their overall assessment score in the gradebook section of Sakai and the score achieved for each question in the assessment section.

Module 1 focusing on the evaluation and interpretation of data included five rubrics in the evaluation of the part III assessment, one for each of the following sub-

skills, separating factual information from inferences, interpreting numerical relationships in graphics, understanding the limitations of correlational data, identifying inappropriate conclusions, and communicating effectively. Four rubrics were used for the analysis of module 2, part III, directed at enhancing students' ability to apply existing knowledge to solve problems in new situations. These four rubrics were directed at identifying and evaluating evidence for a theory, identifying new information that might support or contradict a hypothesis, explaining how new information can change a problem, and communicating ideas effectively. For the third module, creativity in learning and problem solving, five rubrics were used to evaluate the students' ability to separate relevant from irrelevant information, integrating information to solve problems, learning and applying new information, using mathematical skills to solve real-world problems, and communicating ideas effectively. The fourth and final module utilized the rubrics for all 12 sub-skills.

For the purpose of this study, these rubric scores were evaluated in two ways. They were evaluated in relation to each module and each sub-skill. For the module evaluation, the rubric scores for each sub-skill pertaining to a given module were combined. Table 5 shows the number of questions and total points corresponding to each module. For the sub-skill evaluation, the rubric scores for each individual sub-skill were evaluated independently. Each sub-skill was provided two scores, once as part of the associated module (1, 2, or 3) and again as part of module 4, the summation module. Table 6 depicts the sub-skills with their associated module and the number of questions and point values associated with each. The total point values associated with

Table 5: *Module evaluation indicating associated questions and point totals*

Module Number	Number of Questions	Total Points	Communication Evaluated (Yes / No)
1	8	100	Yes
2	6	100	Yes
3	8	100	Yes
4	11	100	Yes

Table 6: *Sub-skill evaluation indicating associated Module, questions, and point values*

Module Number	Sub-skill	Number of Associated Questions	Points Per Question
1	1: Separating factual information from inferences	2	10
	2: Interpreting numerical relationships in graphics	2	10
	3: Understanding limitations of correlational data	2	10
	4: Identifying inappropriate conclusions	2	10
	Communicating ideas effectively	8*	2.5
2	1: Identifying and evaluating evidence for a theory	2	12.5
	2: Identifying new information that might support or contradict a hypothesis	2	12.5
	3: Explaining how new information can change a problem	2	12.5
	Communicating ideas effectively	6*	4.2
3	1: Separating relevant from irrelevant information	2	10
	2: Integrating information to solve problems	2	10

Table 6: *Continued*

3	3: Learning and applying new information	2	10
	4: Using mathematical skills to solve real-world problems	2	10
	Communicating ideas effectively	8*	2.5
4	1: Separating factual information from inferences	1	7
	2: Interpreting numerical relationships in graphics	1	7
	3: Understanding limitations of correlational data	1	7
	4: Identifying inappropriate conclusions	1	7
	1: Identifying and evaluating evidence for a theory	1	7
	2: Identifying new information that might support or contradict a hypothesis	1	7
	3: Explaining how new information can change a problem	1	7
	1: Separating relevant from irrelevant information	1	7
	2: Integrating information to solve problems	1	7
	3: Learning and applying new information	1	7
	4: Using mathematical skills to solve real-world problems	1	7
	Communicating ideas effectively	11*	2.1

* Communicating ideas effectively did not include new questions but was evaluated for all existing questions within the assessment.

each sub-skill are shown in Table 7. This table shows the total values for each sub-skill excluding module 4 and the total values including module 4.

Table 7: Total points associated with each sub-skill, excluding and including module 4

	Sub-skill	Points Per Sub-skill
Excluding Module 4	1: Separating factual information from inferences	20
	2: Interpreting numerical relationships in graphics	20
	3: Understanding limitations of correlational data	20
	4: Identifying inappropriate conclusions	20
	1: Identifying and evaluating evidence for a theory	25
	2: Identifying new information that might support or contradict a hypothesis	25
	3: Explaining how new information can change a problem	25
	1: Separating relevant from irrelevant information	20
	2: Integrating information to solve problems	20
	3: Learning and applying new information	20
	4: Using mathematical skills to solve real-world problems	20
	Communicating ideas effectively	65
	Including Module 4	1: Separating factual information from inferences
2: Interpreting numerical relationships in graphics		27
3: Understanding limitations of correlational data		27
4: Identifying inappropriate conclusions		27
1: Identifying and evaluating evidence for a theory		32
2: Identifying new information that might support or contradict a hypothesis		32
3: Explaining how new information can change a problem		32
1: Separating relevant from irrelevant information		27
2: Integrating information to solve problems		27
3: Learning and applying new information		27
4: Using mathematical skills to solve real-world problems		27
Communicating ideas effectively		88

Use of Health Science Reasoning Test. The Health Science Reasoning Test (HSRT) was given in a pre-test / post-test format. During the first week of the semester and prior to beginning the critical thinking model, all students enrolled in the Critical Thinking in Health Professions course took the HSRT offered by Insight Assessment as a pre-test. Then again during the last week of the semester and after completing the critical thinking model, the same group of students completed the same test, which was designated the post-test. For both the pre-test and the post-test, the assessment was given in an online format, at the same time of day, and in the same classroom. The students logged into the Insight Assessment website to access the exam, entered their random identifier, and began the assessment. Students were given 50 minutes to complete the 33 question exam. Upon completion, the students submitted their multiple choice answer selections and all results were automatically recorded by the administrating agency.

In addition to providing the online testing platform, the agency processed the student results and generated a report for the PI containing the student identifier, numerical scores for the overall assessment, and sub-topic scores for induction, deduction, analysis, inference, and evaluation. They also classify the overall results and sub-topic scores into categories corresponding critical thinking ability. Additionally, the company tracks the minutes the student spent on the test and percent of test completed. If students attempted less than 60% of the test questions or spent less than 15 minutes on the test, Insight Assessment assumed the test results were invalid and that attempt was removed from the statistical analysis provided in the report (Insight Assessment, 2013). This cut off was also adopted for this study.

Insight Assessment defines categories or levels of critical thinking ability based on test scores overall and for each sub-topic. These categories are superior, strong, moderate, and not manifested. The score cutoff for each category varies depending on the total possible score achievable for each sub-topic and not all sub-topics include all categories listed. The ranges for each category are shown in Table 8. Individuals in the superior group are described as having the potential for more advanced learning and leadership, and those with strong scores are labelled as having the potential for academic success and career development. The moderate classification may be associated with challenges with reflective problem solving and reflective decision making associated with learning or employment development. The testing agency suggests students with results falling into the not manifested range may have put forth insufficient effort in the test taking process, suffer from cognitive fatigue, or have difficulties with reading or language comprehension (Insight Assessment, 2013). Once the pre-test and post-test data was received from the testing agency, the PI evaluated the reports and combined the excel document to include both sets of scores. At the conclusion of the semester and implementation portion of the project, the PI evaluated the spreadsheet for missing data. Pre-test and post-test scores not meeting the requirement for a complete test, were removed. Any student that did not have both a complete pre-test and post-test score was eliminated from the study. Additionally, identifiers for students failing to consent to study participation or not meeting inclusion criteria were located and removed at this time.

The PI evaluated the overall scores achieved on the pre-test and post-test for all students meeting the criteria for this study. A two-tailed, paired t-test was applied to

Table 8: *Categorical levels of critical thinking (Insight Assessment, 2013)*

	Not Manifested (points)	Moderate (points)	Strong (points)	Superior (points)
Overall Score	0 - 14	15 - 20	21 - 25	26 - 33
Analysis	0 - 2	3 - 4	5 or more	N/A
Inference	0 - 2	3 - 4	5 or more	N/A
Evaluation	0 - 2	3 - 4	5 or more	N/A
Induction	0 - 4	5 - 7	8 or more	N/A
Deduction	0 - 4	5 - 7	8 or more	N/A

these two sets of data and statistical significance was evaluated with an alpha of 0.05.

The results from the HSRT pre-test / post-test total score analysis served to answer the hypothesis for this study. Additionally, the PI conducted descriptive statistics on this data set and noted the quartile ranges. The change in each total pre-test and post-test score was calculated. Although not involved in hypothesis testing, descriptive statistics and t-tests were conducted for each sub-topic score achieved on the pre-test and post-test to provide additional information on student performance. The number of students falling into each critical thinking category was noted for the overall results and each sub-topic for the pre-test and post-test. Changes in the number of students in each category were noted. The testing agency also reported the amount of time each study participants spent on the assessment. For this study, the time spent on the pre-test was compared to the time spent on the post-test using a two-tailed, paired t-test with an alpha of 0.05. The pre-test value was also subtracted from the post-test value to produce a variable representing the change in time.

Finally, standard linear regression was used to evaluate a relationship between a number of independent variables collected for the study and the change in pre-test and post-test scores, achieved by subtracting the post-test score from the pre-test score. Cases with missing data were replaced with average scores for that variable. The independent variables entered into the model included, GPA, age, gender, primary language, comfort with the English language, ethnicity, educational experience, work experience, Sakai usage, and time spent on the HSRT assessments. The variables pertaining to demographic information were self-reported by the students using the demographic form collected prior to model implementation, these included GPA, age, gender, primary language, comfort with the English language, ethnicity, educational experience, and work experience. The Sakai usage value was based on the number of times each student accessed the reference material in the model and was collected by the PI at the conclusion of the study. Time spent on the HSRT assessment was computed by subtracting the number of minutes spent on the post-test minus the number of minutes spent on the pre-test. These values were reported to the PI by the testing agency.

The significance of the overall model was evaluated at an alpha level of 0.05. The p-value generated from the F-statistic was used to describe the confidence of the model in predicting the outcome for the population. The R squared value for the model was used to evaluate the model's ability to explain the variance in the pre-test and post-test score change. The adjusted R squared value takes into account the number of independent variables in the equation and total number of cases included and adjusts the reflected variance based on these additional factors. The Durbin-Watson statistic is

used to test the assumption that the error deviations for the variables in the regression model are uncorrelated. If correlated, the standard error of the coefficients is underestimated and significance of the findings may be inaccurate.

The sum of squares for regression described the amount of variation explained by the independent variables in the model and the sum of squares for residual described the variation not explained by the independent variables. The degrees of freedom for regression represented the number of independent variables in the model, including the intercept, minus one. The residual degrees of freedom was the difference between this value and one less than the total number of cases included in the evaluation. The sum of squares for each divided by the corresponding degrees of freedom produced the mean square values; the mean square for regression over the mean square for residual produced the F- statistic for the model.

The B coefficient was used to predict the amount of change in the score difference for every one unit change in the independent variable. This coefficient also signified the directionality of that relationship. The standard error was used to determine whether the coefficient was significantly different from zero. The t-value was produced by dividing the coefficient by the standard error. This value was used to establish a p-value and describe significance of that independent variable in relation to the score change prediction. The standardized beta coefficient was adjusted to have a mean of zero and standard deviation of 1. These coefficients were compared between independent variables to determine which has a greater effect on the score change.

Chapter Four - Results

Introduction

The aims of this project were to design a multimodal teaching model to enhance critical thinking in clinical laboratory students, to implement that model into the student curriculum, and to evaluate the success of the model in improving critical thinking in this student population. The null hypothesis proposed for this study was that there is no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. Results in favor of the alternative hypothesis, there is a significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum, would assist in bridging the gap between the critical thinking skill set currently obtained by students completing an education through an accredited institution and the level of critical thinking skills needed by entry level professionals in the work environment.

This chapter will describe the outcomes of this project in relation to the proposed hypothesis and stated aims. This section includes information pertaining to participant demographics, enrollment, consent, and retention. It then describes module validity and evaluation. It also summarizes the implementation and delivery of the model to clinical laboratory technology students, in terms of course and module completion and website usage. Finally, this chapter details the model assessment process and summarizes the

module rubric and Health Science Research Test (HSRT) usage and outcomes. The HSRT pre-test / post-test score change is used to evaluate the proposed hypothesis for this study. The data generated was further investigated to determine whether any demographic characteristics influenced the HSRT total scores. Potential threats to validity and inherit biases were also analyzed.

Study Population and Demographics

Study population. UTMDACC-SHP enrolled 58 junior level students in clinical laboratory technology programs, for the 2013-2014 school year. Of these 58 students, all enrolled in the Critical Thinking in Health Professions course, in addition to one senior student. The senior level student enrolled in the course was allowed to complete the course but was not included in the study due to her education level. One CT student was eliminated from the study because she did not meet the age restriction set by the Institutional Review Board (IRB) requirements. The IRB stipulated that students be 18 years of age or above for study participation. The one student falling below that age requirement was allowed to complete the course but all data was removed from prior to data analysis.

Three students, one CGT and two HTL, did not consent to study participation. All data collected from these three students was removed prior to data analysis.

Additionally three other students chose to drop the course during the semester, one from each of the following programs: MLS, MGT, and HTL. Because these students did not complete the course, they did not complete all module material and did not take the HSRT post-test. Due to an incomplete dataset, these students were excluded from data analysis. Therefore, 51 clinical laboratory students, including 13 MLS students, 20 MGT

students, 11 CGT students, one CT student, and six HTL students completed the majority of the course, met the requirements, and consented to participate in the study.

Insight Assessment designates an HSRT assessment as “complete” when at least 60% of the questions were answered and a minimum of 15 minute were expended on the assessment. The company’s stance is that if the student does meet the time requirement, he did not spend adequate time to consider the material presented. Based on these criteria, all students attempting the pre-test completed the pre-test. However, although all students attempting the post-test met the question completion criteria, four (one from MLS, MGT, CGT, and HTL programs) did not meet the minimum time criteria. These four students showed a negative difference when evaluating the pre-test / post-test change. The data for these students were eliminated due to their failure to adequately complete the primary assessment for this study. Elimination of these students leaves a final sample size of 47 students included for data analysis; 12 MLS (26%), 19 MGT (40%), 10 CGT (21%), one CT (2%), and five HTL (11%). Additionally, there were some students that did not fully complete all modules. Because they completed the majority of the material, they were not eliminated from the data analysis. However, data including and excluding these students will be further evaluated in the statistical analysis section. The student participants and study qualifications are shown in Figure 1.

The proportion of students initially enrolled in each program (MLS, 24%; MGT, 36%; CGT, 21%; CT, 3%; and HTL, 16%) was fairly consistent with enrollment expectations (MLS, 25%; MGT 33%; CGT, 25%; CT, 7%; and HTL, 10%). These proportions also held consistent with study participants. Eighty-one percent of students

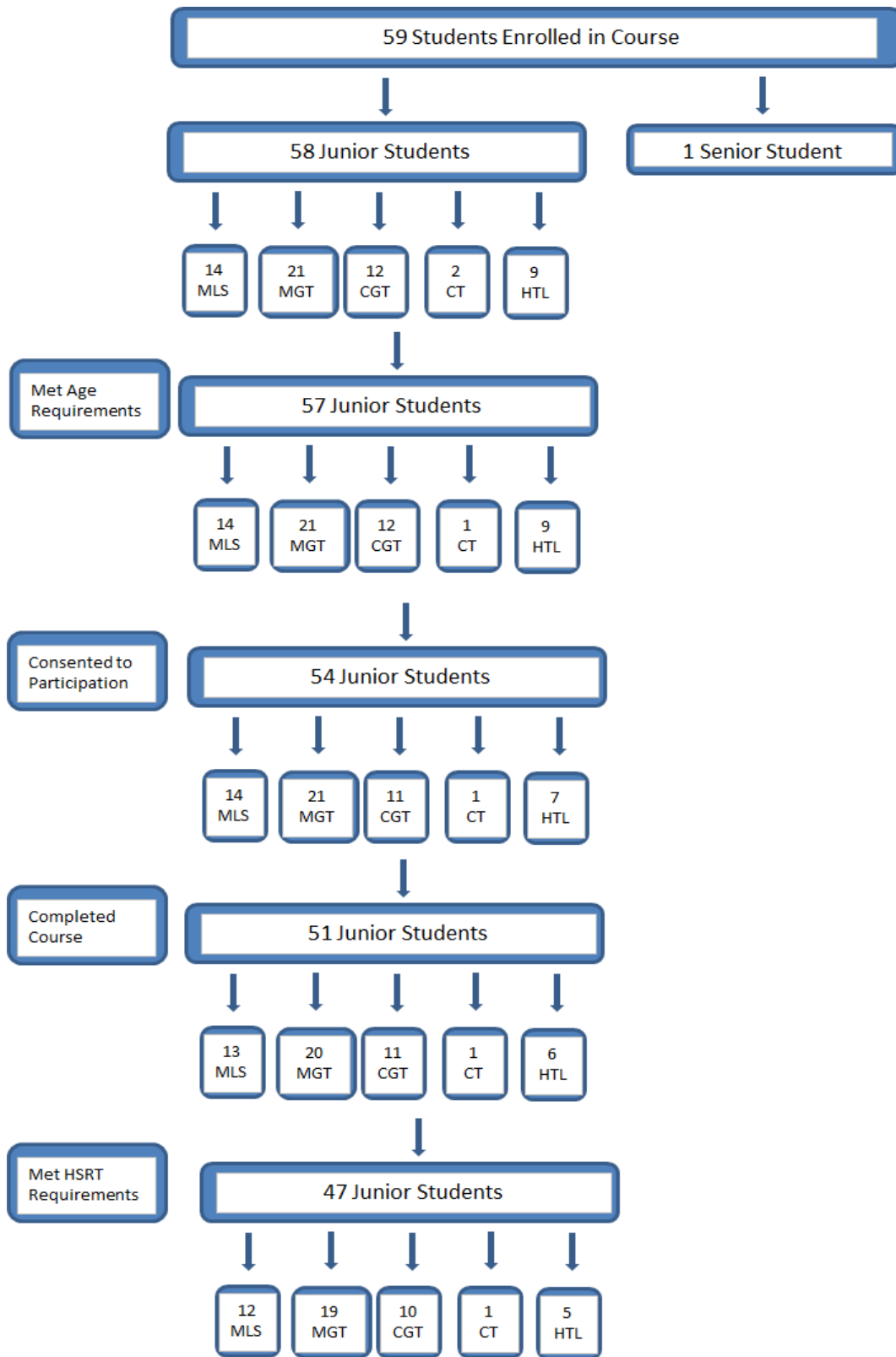


Figure 1. Number of study participants and their qualifications

initially enrolled in the Critical Thinking in Health Professions course, were included in the study. The percentage of students participating in this study from each program is shown in Figure 2.

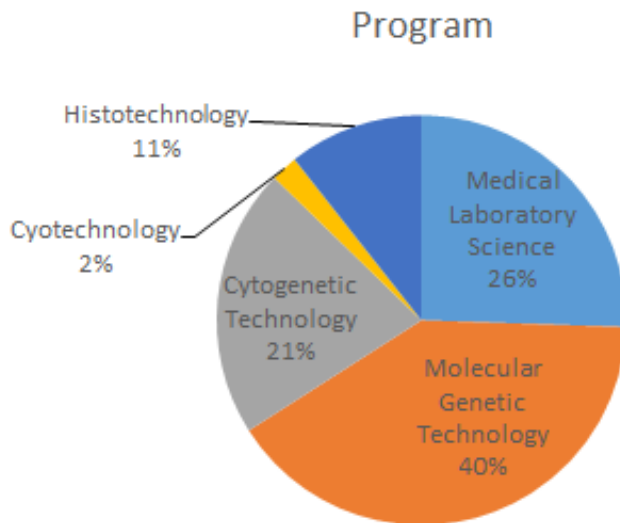


Figure 2. Percentage of students per program

Demographics. All 47 students completed the demographic form in its entirety with options for selection. An option of 'I choose not to answer this question' was provided for multiple topics but this option was never selected by any of the students. However, for the fill in the blank sections, two students chose not to include their age and nine students were unable to complete the GPA section. Therefore, overall percentage data for gender, ethnicity, English as a primary language, work experience, and past educational experience were evaluated from the total population of 47. Age group percentages were calculated using a total of 45 respondents and GPA range percentages from 38 respondents.

Gender. The majority of the students enrolled in the study were female students. The HTL program was unique with more males than females, 60% and 40%,

respectively. The CGT program had equal numbers of males and females, and the CT program only had a single female student. The two largest programs had a larger percentage of females than males. The MLS program consisted of 66.7% females and 33.3% males, and the MGT program had 63.2% females and 36.8% males. The percentage of overall participants by gender is depicted in Figure 3.

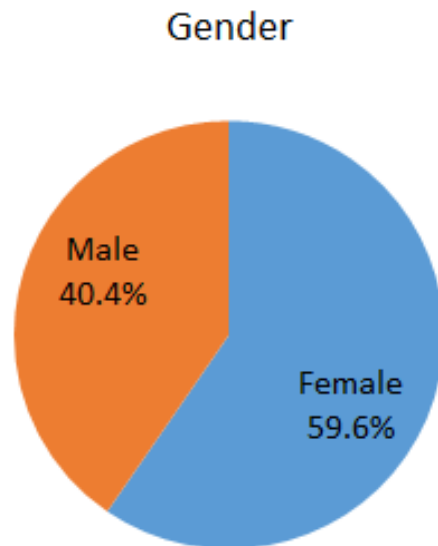


Figure 3. Percentage of students per gender

Ethnicity. All students reported ethnicity. The majority of students (40.4%) reported their ethnicity to align most with the category of White, Caucasian, Anglo American. Of these students, 68.4% were female and 31.6% were male. The second highest ethnicity group reported was Asian, Asian American, Pacific Islanders (25.5%). Of this group, 58.3% were female and 41.7% were male. The Hispanic, Latino, Mexican American ethnicity group followed (21.3%), with 60% females and 40% males. The lowest reported ethnicity group was Black, African American (12.8%). This group included 33.3% females and 66.7% males. No participating students reported

association with the American Indian, Native American ethnicity. The percentage of participating students from each ethnicity group is displayed in Figure 4.

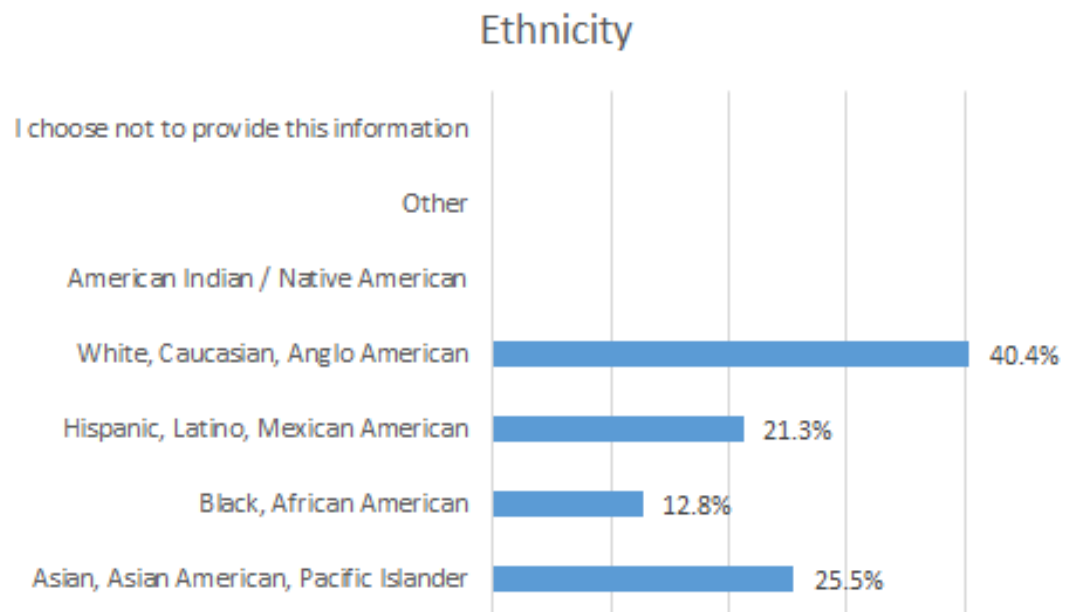


Figure 4. Percentage of students per ethnicity group

Primary language. No students reported a low or poor comfort level with the English language. The majority of students (63.8%) enrolled in this study reported English as their primary language. Of the students reporting English as their primary language, 86.7% reported an excellent comfort level with this language; and 13.3% reported a good comfort level. For those students that do not have English as a primary language, 29.4% reported an excellent comfort level with English, 41.2% reported a good comfort level, and 29.4% reported a moderate comfort level with English. Of the five students reporting only a moderate comfort level, the majority (80%) was of the Asian, Asian American, Pacific Island ethnicity group; one individual belonged to the White, Caucasian, Anglo American group. The percentage of students reporting English as their primary language is shown in Figure 5, along with their reported comfort level.

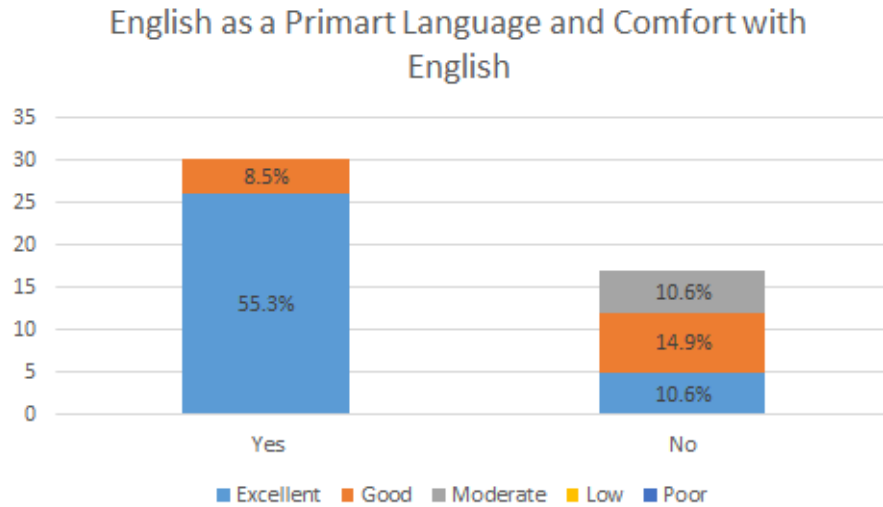


Figure 5. Percentage of students with English as primary language and their level of comfort

Work experience. The majority of students participating in the study (70.2%) reported having never worked in a laboratory environment. Nineteen percent reported working in a laboratory environment for less than 2 years. Only 4.3% of students reported working in a laboratory environment for two to five years, and 6.4% reported working in a laboratory environment for greater than five years. The percentage of students in each category for years of work experience is presented in Figure 6.

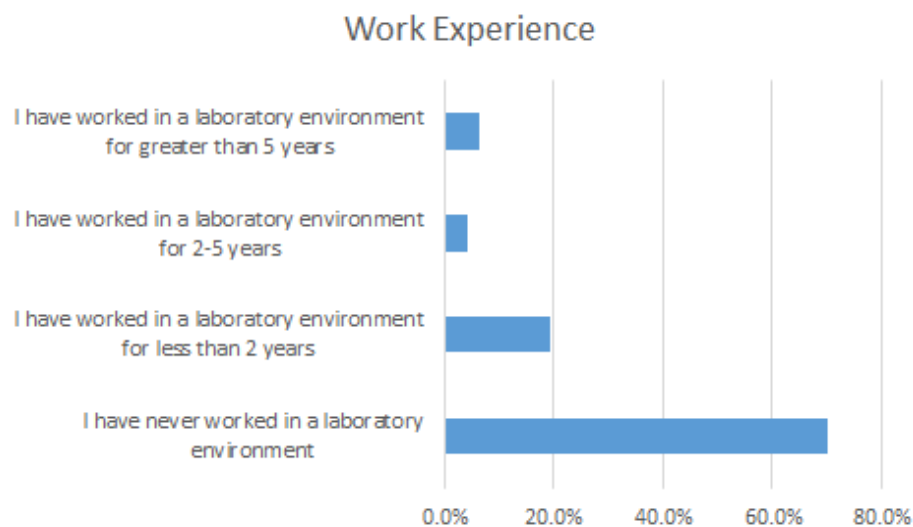


Figure 6. Percentage of students with each level of work experience

Educational experience. For past educational experience, no students reported having any degree higher than a bachelor’s degree. Thirteen percent of participating students reported having attended a four-year university and 17.0% reported having obtained a bachelor’s degree prior to enrollment in a clinical laboratory technology program at UTMDACC-SHP. However, the majority of students (70.2%) reported attending a junior college or community college. Of the eight students reporting having received a bachelor’s degree prior to enrollment into this program, 75% percent reported having no laboratory experience, 25% reported working in a laboratory for less than two years, 25% reported having worked in a laboratory for two to five years, and none reported greater than five years of laboratory experience. The percentage of students for each past educational experience category is shown in Figure 7.

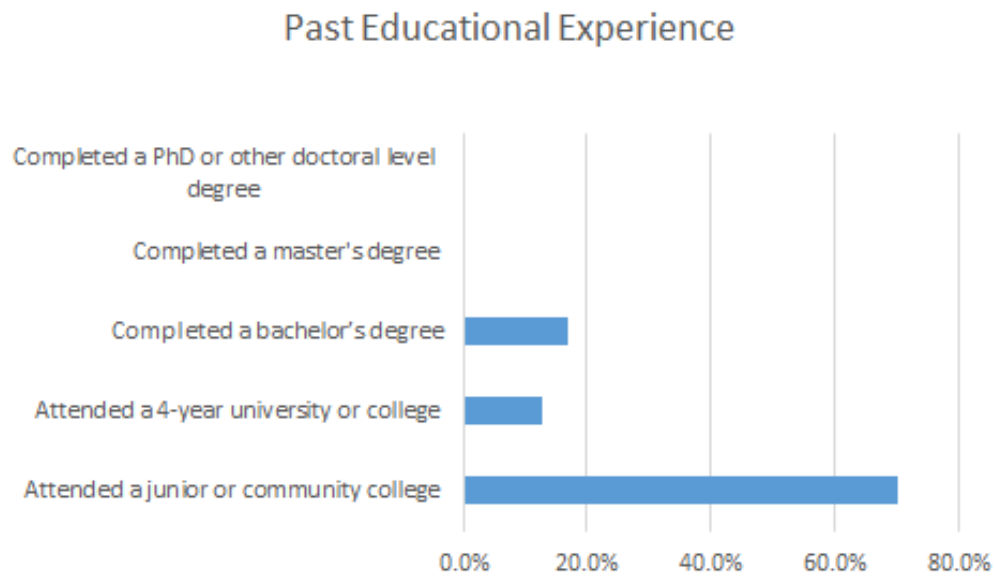


Figure 7. Percentage of students with each level of past educational experience

Age. The age of participants ranged from 19 to 52 with two students choosing not to provide an answer to this question. The most common age reported was 22 years old, while the median value was 24 years. The average age was calculated to be 27

years with a standard deviation of 8. The reported ages were divided into five year intervals beginning at the minimum allowable age of 18. Based on these ranges, the majority of responding students (37.8%) fell into the 18 to 22 year old category, typical age range for third year college students. The next most common age range for participating students (31.1%) was 24 to 27 years of age. The percentage of students falling into each age range is displayed in Figure 8.

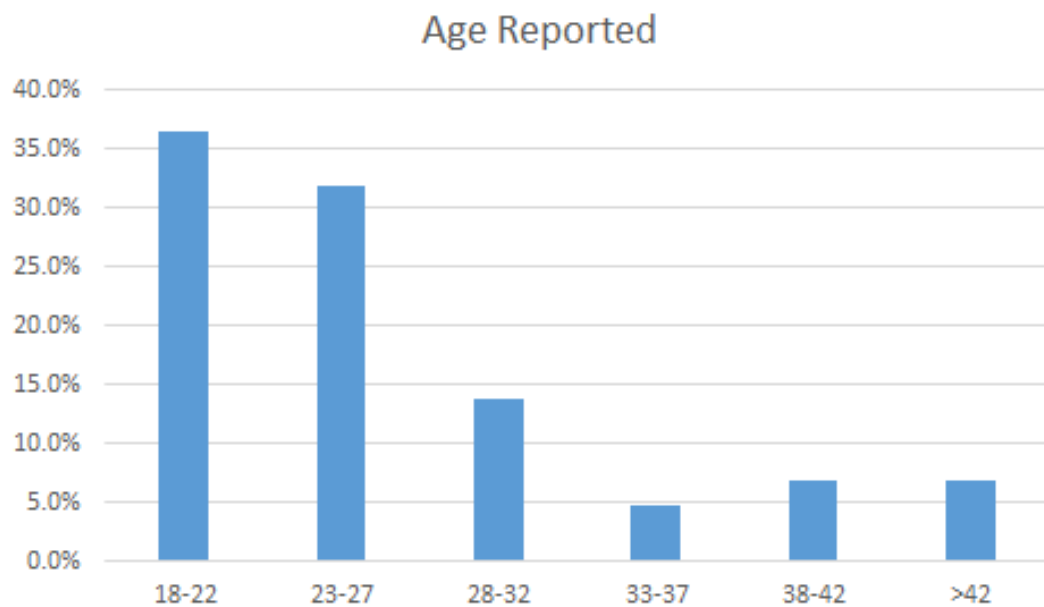


Figure 8. Percentage of students in each age group

Grade point average. Reported GPA values ranged from 2.5 to 4.0 with nine students choosing not to answer this question. Of those that did not answer, several reported not knowing this value. The average GPA calculated for this student population was 3.5 with a standard deviation of 0.4. The median and mode for this group of students was also 3.5. The values reported for GPA were categorized into 0.5 ranges. The majority of values for those responding (47.4%) fell into the 3.6-4.0 range. This categorized data and percentage of students per group is shown in Figure 9.

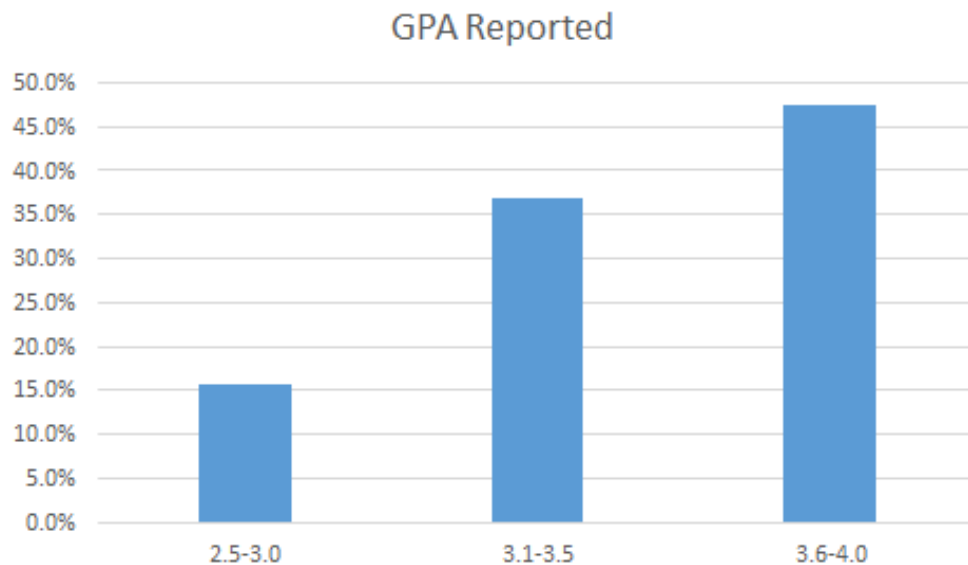


Figure 9. Percentage of students in each GPA range

Module Validity

Faculty evaluation. Five faculty members from UTMDACC-SHP were asked to review the critical thinking model prior to implementation, using the evaluation form in Appendix D. This evaluation form was used to assess the validity of the model. All invited faculty members participated and submitted evaluation documents by the date requested. One evaluator failed to answer a single portion of one question. This evaluator indicated not applicable when asked to rank instructor presence. All other sections and questions were completed.

Evaluators were asked to assess content validity by ranking the ability of the reference and assessment material used in part I of each module to address the 11 targeted sub-skills (see Table 9). The lowest average ranking for this question was a 4.0; this score corresponded to sub-skill 4 in module 1, identifying inappropriate conclusions. Three evaluators suggested expanding the PowerPoint presentation information to include an example. The second lowest average ranking was a 4.2 and

Table 9: Average faculty rating for sub-skills related to part I of each module (N=5)

Question 1: To what degree does the reference material and assessment material found in Part I of Modules 1-3 address each sub-skill?				
Module 1: Effectively Evaluating and Interpreting Data				
Sub-skill	1: Separating Factual Information From Inferences	2: Interpreting Numerical Relationships in Graphics	3: Understanding the Limitations of Correlational Data	4: Identifying Inappropriate Conclusions
Average	4.4	4.6	4.4	4.0
Standard deviation	0.55	0.55	0.55	0.71
Module 2: Applying Existing Knowledge to Solve Problems in New Situations				
Sub-skill	1: Identifying and Evaluating Evidence for a Theory	2: Identifying New Information That Might Support or Contradict a Hypothesis	3: Explaining How New Information Can Change a Problem	
Average	4.2	4.6	4.6	
Standard deviation	0.84	0.55	0.55	
Module 3: Creativity in Learning and Problem Solving				
Sub-skill	1: Separating Relevant from Irrelevant Information	2: Integrating Information to Solve Problems	3: Learning and Applying New Information	4: Using Mathematical Skills to Solve Real-world Problems
Average	4.6	4.6	4.6	4.6
Standard deviation	0.55	0.55	0.55	0.55

Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

corresponded to sub-skill 1 in module 2, identifying and evaluating evidence for a theory. Comments made by only one evaluator included, rewording an assessment question to improve clarity, and providing more background information before introducing a tool for working with the sub-skill. The other nine sub-skills resulted in average scores of 4.4 or 4.6. Overall, evaluators stated that they liked the terms and concept sheets for each module and that they found the different color schemes corresponding to different modules useful for organization.

In order to address the constructive comments pertaining to the part I reference and assessment material, an example was added to the PowerPoint slide presentation provided for module 1 sub-skill 4 to improve the reference material provided for identifying inappropriate conclusions. A non-science scenario was provided, along with slides identifying potential assumptions, biases, and additional information that might be needed to evaluate the situation. The first assessment question for module 2 sub-skill 1, identifying and evaluating evidence for a theory, was reworded as suggested by the evaluator, to clarify the intent of the question. More background information was provided for this sub-skill with the addition of three PowerPoint slides at the beginning of the presentation. The three new slides were provided to define theories and constructs, the process for evaluating a theory, and provide more information on concept maps and their usefulness in identifying and evaluating evidence for a theory.

An additional question, addressing content validity, asked the evaluators to rank the degree to which the reference and assessment material in part II of each module addressed the sub-skills related to that module. For this question, all sub-skills received an average score of 4.6. General comments for this section indicated a broken website link and a concern related to the level of technical background students would need to correctly answer the assessment questions. However, positive comments noted the benefit of reminder videos, the interactive format, and incorporation of issues related to their professional lives. Each of the constructive and positive comments was made by a single evaluator. Table 10 displays the average rating for part II of each module and sub-skill.

Table 10: Average faculty rating for sub-skills related to part II of each module (N=5)

Question 2: To what degree does the reference material and assessment found in Part II of each module address all associated sub-skills?					
Module 1: Effectively Evaluating and Interpreting Data					
Sub-skill	1: Separating Factual Information From Inferences	2: Interpreting Numerical Relationships in Graphics	3: Understanding the Limitations of Correlational Data	4: Identifying Inappropriate Conclusions From Inferences	Communication
Average	4.6	4.6	4.6	4.6	4.6
Standard deviation	0.55	0.55	0.55	0.55	0.55
Module 2: Applying Existing Knowledge to Solve Problems in New Situations					
Sub-skill	1: Identifying and Evaluating Evidence for a Theory	2: Identifying New Information That Might Support or Contradict a Hypothesis	3: Explaining How New Information Can Change a Problem	Communication	
Average	4.6	4.6	4.6	4.6	
Standard deviation	0.55	0.55	0.55	0.55	
Module 3: Creativity in Learning and Problem Solving					
Sub-skill	1: Separating Relevant from Irrelevant Information	2: Integrating Information to Solve Problems	3: Learning and Applying New Information	4: Using Mathematical Skills to Solve Real-world Problems	Communication
Average	4.6	4.6	4.6	4.6	4.6
Standard deviation	0.55	0.55	0.55	0.55	0.55

Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

The broken web link was identified and corrected in the part II reference material. With the correction of this link, all web links worked as intended. Although one evaluator expressed a concern with the level of background information needed by the students to correctly answer the questions, the level was not adjusted. No other evaluator mentioned this concern and the overall rating for the level of reference material provided was 4.6 out of 5.0.

A third question addressing content validity focused on the degree to which the reference and assessment material in part III of each module and module 4 addressed all related sub-skills. Three sections received an average score of 4.2, while all others received a 4.4 or 4.6. The sub-skills that received an average score of 4.2 were, module 2 sub-skill 3, explaining how new information can change a problem and two sub-skills included in module 4, identifying new information that might support or contradict a hypothesis and separating relevant from irrelevant information. There were no comments included that specifically related to these sub-skills. However, overall, one evaluator was concerned that for module 2, some students might have difficulties digesting and applying the reference information. For module 4, one evaluator wanted clarification about the inclusion of new reference material, or the lack there of, for this section. Two comments mentioned the benefit of providing grading rubrics but that the text size should be increased for clarity. Tables 11 and 12 indicate the average rating for each sub-skills and related module part III and module 4, respectively.

The reference material for module 2 was not altered based on the single faculty comment concerning the difficulty level. The comment did not prove any specific information for content modification, and applying existing knowledge to solve new problems is the primary goal of module 2. The skill set needed to perform this process should have been gained through parts I and II of the module. The PowerPoint for module 2 sub-skill 1, identifying and evaluating evidence for a theory, was expanded upon based on previous evaluator comments. However, the other sub-skills did not receive any criticism or concern. A text information link was added to the module 4 folder to clarify that no additional reference information or sub-skills were needed for

Table 11: Average faculty rating for sub-skills related to part III of each module (N=5)

Question 3: To what degree does the assessment found in Part III of Modules 1-3 and Module 4 address all associated sub-skills?					
Module 1: Effectively Evaluating and Interpreting Data					
Sub-skill	1: Separating Factual Information From Inferences	2: Interpreting Numerical Relationships in Graphics	3: Understanding the Limitations of Correlational Data	4: Identifying Inappropriate Conclusions From Inferences	Communication
Average	4.6	4.6	4.6	4.6	4.4
Standard deviation	0.55	0.55	0.55	0.55	0.89
Module 2: Applying Existing Knowledge to Solve Problems in New Situations					
Sub-skill	1: Identifying and Evaluating Evidence for a Theory	2: Identifying New Information That Might Support or Contradict a Hypothesis	3: Explaining How New Information Can Change a Problem	Communication	
Average	4.6	4.6	4.2	4.4	
Standard deviation	0.55	0.55	0.84	0.55	
Module 3: Creativity in Learning and Problem Solving					
Sub-skill	1: Separating Relevant from Irrelevant Information	2: Integrating Information to Solve Problems	3: Learning and Applying New Information	4: Using Mathematical Skills to Solve Real-world Problems	Communication
Average	4.6	4.4	4.6	4.6	4.6
Standard deviation	0.55	0.89	0.55	0.55	0.55

Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

Table 12: Average rating for sub-skills related to module 4 (N=5)

Question 3: To what degree does the assessment found in Part III of Modules 1-3 and Module 4 address all associated sub-skills?				
Module 4: Incorporation of All Skills Presented				
Sub-skill	1: Separating Factual Information From Inferences	2: Interpreting Numerical Relationships in Graphics	3: Understanding the Limitations of Correlational Data	4: Identifying Inappropriate Conclusions From Inferences
Average	4.4	4.4	4.4	4.4
Standard deviation	0.55	0.55	0.55	0.55
Module 2: Applying Existing Knowledge to Solve Problems in New Situations				
Sub-skill	1: Identifying and Evaluating Evidence for a Theory	2: Identifying New Information That Might Support or Contradict a Hypothesis	3: Explaining How New Information Can Change a Problem	
Average	4.4	4.2	4.4	
Standard deviation	0.55	0.84	0.55	
Module 3: Creativity in Learning and Problem Solving				
Sub-skill	1: Separating Relevant from Irrelevant Information	2: Integrating Information to Solve Problems	3: Learning and Applying New Information	4: Using Mathematical Skills to Solve Real-world Problems
Average	4.2	4.4	4.4	4.4
Standard deviation	0.84	0.55	0.55	0.55
Sub-skill	Communication			
Average	4.4			
Standard deviation	0.55			

Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

this cumulative module. The text link further provided clarification as to the purpose of this module and the importance of reviewing and using previous reference information related to the 12 sub-skills introduced previously within this course. In order to make the rubric easier to view, each sub-skill was moved to a separate slide and the font sized was increased to Calibri 14.

A single question on the evaluation form targeted the construct validity of the study and asked evaluators to rank the degree to which each module and associated part addressed critical thinking. For this question, all sections received an average score of 4.6. The only comment associated with this question stated that obvious effort and thought was included in the course design and that it would help improve critical thinking skills in clinical laboratory students. The average rating describing the ability of each module and associated part to address critical thinking overall is shown in Table 13.

Table 13: *Average faculty rating for each module and part related to critical thinking (N=5)*

Question 4: To what degree does each module and associated parts address critical thinking?											
	Module 1			Module 2			Module 3			Module 4	Overall
Part	I	II	III	I	II	III	I	II	III		
Average	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Standard deviation	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

The final question aimed to address face validity and targeted the model design, topic chosen, amount of reference material, level of reference material, level of assessment, ease of use or navigation, platform chosen, delivery method, instructor presence, and usefulness of feedback. The lowest average score produced for this question was related to instructor presence at 4.0. Three comments were made related to this topic. One evaluator wanted clarification about the availability of face-to-face class sessions and tutorial sessions. Another suggested stressing the asynchronous nature of the course and the other provided tips for relaying video information to students with more open body language.

Two topic related to this question received an average rating of 4.2 and all others received a 4.4, 4.6, or 4.8. One receiving a 4.2 related to the amount of reference material provided. The only comment related to his question suggested slightly reducing the amount of reference material. The other topic receiving an average rating of 4.2 was delivery method. One evaluator suggested that blended learning may be more beneficial for some students that might need additional help grasping the concepts. Another evaluator stated that the delivery method was great. The topic receiving the highest average rating was topic chosen with an average score of 4.8. Two comments suggested that the topic was relatable and relevant to the targeted student population. Table 14 indicates the average rating for various topics related to the design, implementation, and assessment of the model.

A course announcement was added, in addition to the instructor video clips, to stress the nature of the course. Students were reminded of the asynchronous format

Table 14: Average faculty rating for design, implementation, and assessment aspects of the model (N=5)

Question 5: Please rank the following:										
Aspect	Model design	Topic	Amt. Ref. Mat.	Level Ref. Mat.	Level Assess.	Ease of Use	Platform	Delivery Method	Instr. Pres.	Feedback
Average	4.6	4.8	4.2	4.6	4.6	4.6	4.6	4.2	4.0	4.6
Standard deviation	0.55	0.45	0.84	0.55	0.55	0.55	0.55	0.84	0.82	0.55

Ref. = Reference; Mat. = Material; Assess. = Assessment; Instr. = Instructor; Pres. = Presence
Likert scale: 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good

and the option to work at their own pace while completing the course in a timely manner. They were also again provided with information for instructor and peer interactions via discussion board, live chat, and email. Due to the goals of this project, blended learning with face-to-face sessions was not provided. The videos were not rerecorded to adjust for body language; however, announcements and comments were modified to stress the accessibility of the instructor and to try and improve instructor presence in the overall course.

Student evaluation. Upon completion of the course content, the students voluntarily completed a survey (Appendix E) describing various aspects of their experience with the project. Of the 53 students completing the course, only five completed the entire student evaluation, giving a response rate of 9%. The response rate was likely low because the link was made available for students to complete on their own time, after the conclusion of the semester. The link was provided within Sakai and sent out via email; no due date was set and no reminders were sent. The first three questions and part of question six were completed by six students; only five students

completed the remainder of the questions. The results, in percentages, are out of the total number of respondents and all response values were reported based on the number of responses received.

The first four questions target the organization of the course in terms of modules and parts, online delivery style, course content and concepts, and topics of lung cancer and laboratory testing. The majority of students (66.67%) responding to the evaluation indicated that the organization of the course was excellent. A single additional comment stated that the course was very well organized. Most of the respondents (66.67%) indicated that the delivery style was okay. Comments for this question were each made by a single student and included, the feedback was too general, enjoyed working independently and at own pace, and the sample questions were helpful. In response to a question concerning the views on course content, the majority of students (50%) indicated that the content was okay. One student commented that the critical thinking aspect was not challenging, while another found the process of reviewing and analyzing various information sources was beneficial. Sixty percent of respondents felt the topic of lung cancer and laboratory testing was excellent. Some students stated that they enjoyed the topic and found it made the course more interesting and exciting, while others noted that the unfamiliar topic made dealing with the critical thinking concepts more difficult. Table 15 indicates the full set of results for each of these questions.

The next question aimed at evaluating the degree to which the students felt that the sub-skills were addressed for each module. For all sections, the majority of respondents indicated that the degree to which the sub-skills were addressed for each module and part was either excellent or okay. For all but one portion of the question,

Table 15: *Student response percentages and number of respondents for course organization, delivery style, content, and topic (N=6 for questions 1, 2, and 3; N=5 for question 4)*

Question 1	Select the option that best reflects your view of the organization of the course, in terms of modules and parts. Feel free to add comments related to this topic below.	
Answer Choice	Responses (percent)	Responses (number)
Excellent	66.67	4
Okay	16.67	1
Questionable	0	0
Poor	16.67	1
Question 2	Select the option that best reflects your view of the delivery style of the course, in terms of online format. Feel free to add comments related to this topic below.	
Answer Choice	Responses (percent)	Responses (number)
Excellent	33.33	2
Okay	66.67	4
Questionable	0	0
Poor	0	0
Question 3	Select the option that best reflects your view of the course content, in terms of concepts addressed. Feel free to add comments related to this topic below.	
Answer Choice	Responses (percent)	Responses (number)
Excellent	33.33	2
Okay	50	3
Questionable	0	0
Poor	16.67	1
Question 4	Select the option that best reflects feelings concerning the course topic of lung cancer and laboratory testing.	
Answer Choice	Responses (percent)	Responses (number)
Excellent	60	3
Okay	0	0
Questionable	40	2
Poor	0	0

two of the five respondents indicated excellent, two indicated okay, and one indicated poor. For module 1 sub-skill 4, three respondents selected excellent, while one indicated okay, and one indicated poor. The two comments both addressed module 3

sub-skill 4, using mathematical skills to solve real-world problems. One student stated that the math was hard to get through, while another commented on liking the math. This second student also mentioned the benefit of learning from communication errors and the benefit of working with algorithms and case studies to future course work. The complete list of responses by percentage is shown in Table 16.

An additional question asked the respondents to rate the usefulness of the reference materials supplied for each module. The majority of respondents described these resources as being either very useful or somewhat useful. In reference to the introduction section, only five students responded with two indicating very useful, two selecting somewhat useful, and one identifying the reference material as not really useful. For all other sections, only one student indicated that the reference material supplied was not very useful. For module 3 part II and module 3 part II, three students described the reference material as very useful and two identified it as somewhat useful. For all other modules and parts, two students found the material very useful, while three found it somewhat useful. The only comment supplied for this section mentioned that the PowerPoints were not very useful but that the background information was useful. This needs to be interpreted with caution because it is from a single reviewer. However, based on this comment, the student may have simply preferred other modalities of content delivery or the Powerpoints may need some revision to maximize their usefulness. Table 17 provides the response percentages.

The following three questions were free response and asked about the best and worst parts of the course, and changes that could be made to improve the course. Three students noted the online format and self-paced nature of the course as their

Table 16: Student response percentages and number of respondents for the degree to which sub-skills were addressed in each module (N=5)

Question 5		To what degree do you feel that each of the following objectives or sub-skills were met:							
Module 1: Effectively Evaluate and Interpret Data									
Sub-skills	1: Separating Factual Information from Inferences		2: Interpreting Numerical Relationships in Graphics		3: Understanding the Limitations of Correlational Data		4: Identifying Inappropriate Conclusions		
Answer Choice	Responses (%) (no.)		Responses (%) (no.)		Responses (%) (no.)		Responses (%) (no.)		
Excellent	40	2	40	2	60	3	60	3	
Okay	40	2	40	2	20	1	20	1	
Questionable	0	0	0	0	0	0	0	0	
Poor	20	1	20	1	20	1	20	1	
Module 2: Apply Existing Knowledge to Solve Problems in New Situations									
Sub-skills	1: Identifying and Evaluating Evidence for a Theory		2: Identifying New Information that Might Support or Contradict a Hypothesis		3: Explaining How New Information can Change a Problem				
Answer Choice	Responses (%) (no.)		Responses (%) (no.)		Responses (%) (no.)				
Excellent	40	2	40	2	60	3			
Okay	40	2	40	2	20	1			
Questionable	0	0	0	0	0	0			
Poor	20	1	20	1	20	1			
Module 3: Creativity in Learning and Problem Solving									
Sub-skills	1: Separating Relevant from Irrelevant Information		2: Integrating Information to Solve Problems		3: Learning and Applying New Information		4: Using Mathematical Skills to Solve Real-world Problems		
Answer Choice	Responses (%) (no.)		Responses (%) (no.)		Responses (%) (no.)		Responses (%) (no.)		
Excellent	40	2	40	2	60	3	60	3	
Okay	40	2	40	2	20	1	20	1	
Questionable	0	0	0	0	0	0	0	0	
Poor	20	1	20	1	20	1	20	1	
Communication									
Answer Choice	Responses (%) (no.)								
Excellent	40	2							
Okay	40	2							
Questionable	0	0							
Poor	20	1							

% = percent; no. = number

Table 17: Student response percentages and number of respondents for the degree to which reference materials were useful for each module (N=5 for introduction; N=6 for all other parts)

Question 6		Rate the usefulness of the reference material for each module and part:					
	Introduction						
Answer Choice	Responses (%) (no.)						
Very Useful	40 2						
Somewhat Useful	40 2						
Not Very Useful	20 1						
Module 1: Effectively Evaluate and Interpret Data							
	Part I	Part II		Part III			
Answer Choice	Responses (%) (no.)	Responses (%) (no.)		Responses (%) (no.)			
Very Useful	33.33 2	33.33	2	33.33	2		
Somewhat Useful	50 3	50	3	50	3		
Not Very Useful	16.67 1	16.67	1	16.67	1		
Module 2: Apply Existing Knowledge to Solve Problems in New Situations							
	Part I	Part II		Part III			
Answer Choice	Responses (%) (no.)	Responses (%) (no.)		Responses (%) (no.)			
Very Useful	33.33 2	33.33	2	33.33	2		
Somewhat Useful	50 3	50	3	50	3		
Not Very Useful	16.67 1	16.67	1	16.67	1		
Module 3: Creativity in Learning and Problem Solving							
	Part I	Part II		Part III			
Answer Choice	Responses (%) (no.)	Responses (%) (no.)		Responses (%) (no.)			
Very Useful	33.33 2	50	3	50	3		
Somewhat Useful	50 3	33.33	2	33.33	2		
Not Very Useful	16.67 1	16.67	1	16.67	1		

% = percent; no. = number

favorite aspect. Three others described the case studies, material, and relevant topic as the most beneficial aspect of the course. For the worst features of the course, two students commented on the length of the articles and amount of reference material, two

commented on the feedback given and requested more timely and specific response, and two others indicated not applicable. When asked about improvements, one student again responded with not applicable, one requested more familiar subject matter, one noted the format of some of the reference material, and two others again requested more thorough feedback. The next question asked the students whether or not they found the course beneficial overall. The majority (66.67%) responded with yes. The complete percentages relating to responses about the overall course are shown in Figure 10.

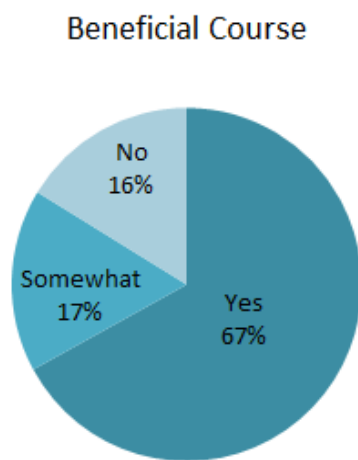


Figure 10. Percentage of students finding the course beneficial

Module Implementation and Delivery

Module completion. The complete model consisted of 19 assessments. Completion was determined by submission of a completed assessment by the designated due date. Students that did not submit all modules were not eliminated from the study. However, the HSRT pre-test and post-test data were evaluated with and without these individuals to see if non-completion of any sections makes a difference in the models ability to improve critical thinking skills based on the difference in pre-test and post-test HSRT scores. For this analysis, the pre-test and post-test HSRT scores

were removed for students with missing modules and the HSRT numerical scores were re-analyzed looking for a statistically significant difference in these two values with a paired t-test and an alpha of 0.05. Additionally, the data from these students was not available for the module analysis.

Eighty-three percent of students completed all assessments within the model. Eleven percent of study participants were missing a single assignment, 2% failed to complete three assignments, 2% were missing four assignments, and an additional 2% failed to complete five assignments. Although part I and II of each module was graded on completion rather than correctness, these portions were important for students to practice the skills needed for part III and module 4. Module 4 incorporated all skills learned throughout the model. Six percent of all study participants failed to complete the cumulative module 4 and 13% failed to complete at least one practice section. One student fell into both groups, with a missing cumulative module and several missing practice sessions. The number of students failing to complete assignments and the type of assignment are shown in Figure 11.

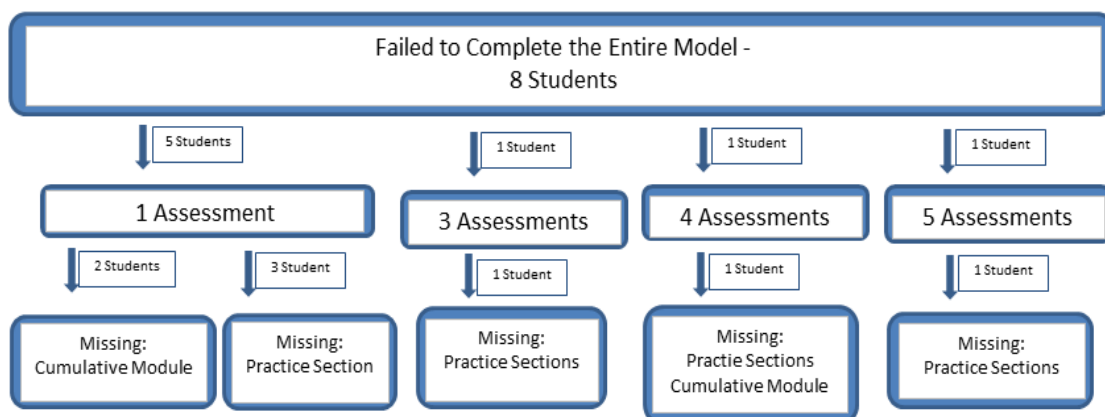


Figure 11. Number of students failing to complete model and type of missing assignment

Access and usage. The overall visit statistics for Sakai showed that 100% of students enrolled in the course visited the site during the span of the semester long course. The site was opened to students in August but the course did not begin until September. Visit statistics showed that 39 individual students accessed the site during the month of August and all 58 accessed the site during the month of September. The course continued through October and November before concluding in December. Visit statistics for October indicated that all 58 students visited the site. In November, this number is lower, at 55, because three students had dropped the course. This number is again lower in December, at 54, because an additional student dropped the course. Based on the view statistics, the site was most frequently viewed in October, followed by November, September, December, and finally August. The full view statistics for unique visits to the site and total visits to the site are indicated in Figure 12.

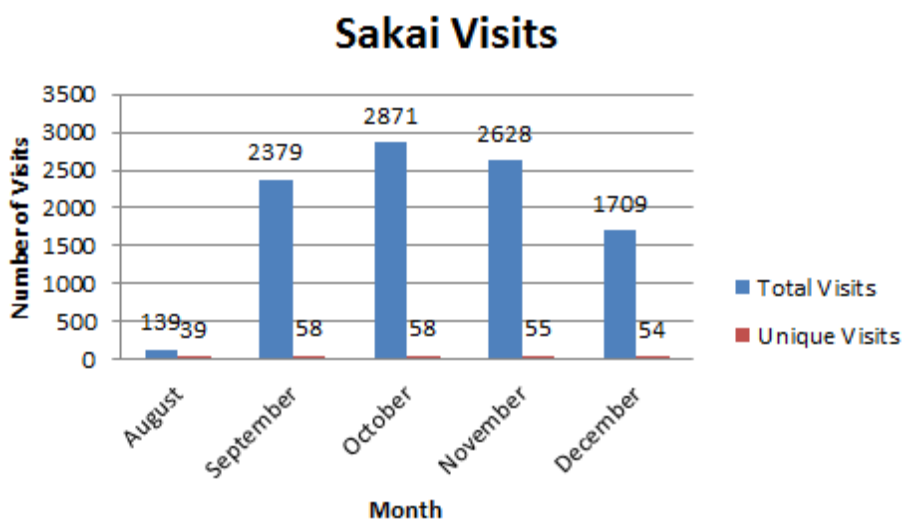


Figure 12. Number of student visits to Sakai by month

The Sakai activity statistic tracked students' utilization of the references, assessments, course information, email, discussion boards, and roster tools available to them. This statistics did not track the activity of other tools, such as announcements,

schedule, live chats, and gradebook. Of the activities tracked, the resource tool received the highest percentage of the activity at 78.7%. A more descriptive resource statistic for this section indicated that 73 files or folders were contained in this section and that 100% of those were opened by Sakai users enrolled in this course. The tool or section receiving the second highest activity level was the assessment section with 13.7% of the activity. Of the communication options tracked, email (2.8%) received a higher percent utilization than discussion boards (0.9%). The students were required to review the resources and take the assessments; however, the communication modalities were optional. The percent activity for each tool is shown in Figure 13.

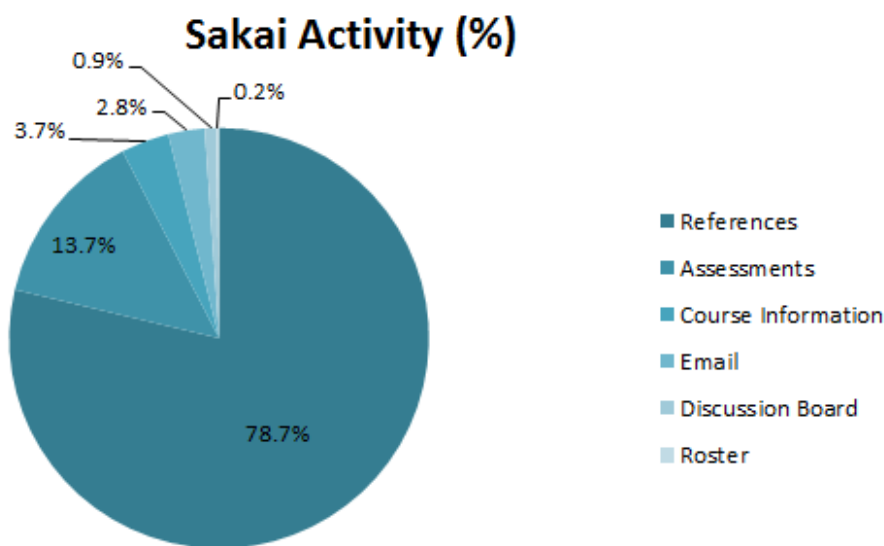


Figure 13. Sakai percent activity for each tool tracked

Model Assessment

Rubric scores. Rubrics were used to score assessments with questions related to each sub-skill in the model. The scored assessments were associated with the third part of each module, as well as with module 4. These scores were evaluated in relation to each module and for each sub-skill.

Model evaluation. For the module evaluation, the averages and standard deviations for each part III and module 4 are shown in Figure 14. The data for students with missing module assessments for the cumulative module were removed for all module analyses. Therefore, the module analysis consists of data from 44 study participants. The average rubric score was highest for module 1 (91.2), followed by module 4 (85.4), module 2 (84.2), and module 3 (82.9). However, when taking the standard deviation into account, these values were not significantly different. With 75 considered a passing score, only one student failed to pass module 1, part III. With the same passing cut-off, eight students failed to pass module 2, part III, eight students failed to pass module 3, part III, and four students did not successfully complete module 4.

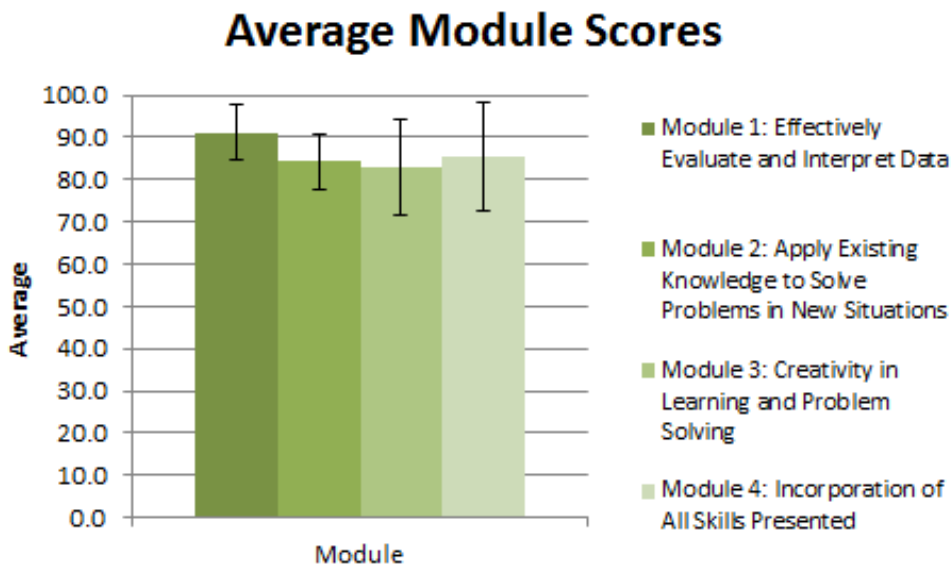


Figure 14. Average grades and standard deviation values for part III of each module and module 4

Sub-skill evaluation. For the evaluation of each sub-skill, the value provided is a percentage of the total value available. These sub-skills were initially evaluated per module and then re-evaluated including the portion from module 4. When module 4 was

evaluated separately, all sub-skills for module 1 and module 3 were based on a 20 point maximum score. When the related sub-skills from module 4 were included, the maximum score increased to 27 for each sub-skill. For module 2, when the sub-skills were evaluated separate from module 4, the maximum point value for each and communication was 25. When the module 4 contribution was added, the maximum value increased to 32 for each sub-skill. The combined communication score was evaluated for all modules together, with a maximum value of 88. All values were adjusted to percentages for analysis of the sub-skills for each individual module and for the sub-skills combined with the contribution from module 4. Because three study participants had missing values for module 4, all data is based on averages for 44 students.

The data is similar for the average sub-skill scores including and excluding module 4 values. In both cases, all sub-skill averages were in the passing range, with passing defined as 75 or above. The highest average was observed for module 1, sub-skill 2, interpreting numerical relationships on graphics and the lowest average was seen for module 2, sub-skill 1, identifying and evaluating evidence for a theory. Although the averages were slightly different depending on whether or not module 4 was included, there was no significant difference between these results for any of the sub-skills evaluated. When looking at individual student performances, students had the most difficulty module 2, sub-skill 1, identifying and evaluating evidence for a theory; module 3, sub-skill 1, separating relevant and irrelevant information; and module 3, sub-skill 4, using mathematical skills to solve real-world problems. The data is displayed in Figures 15 and 16, respectively.

Average Sub-skill Score Excluding Module 4

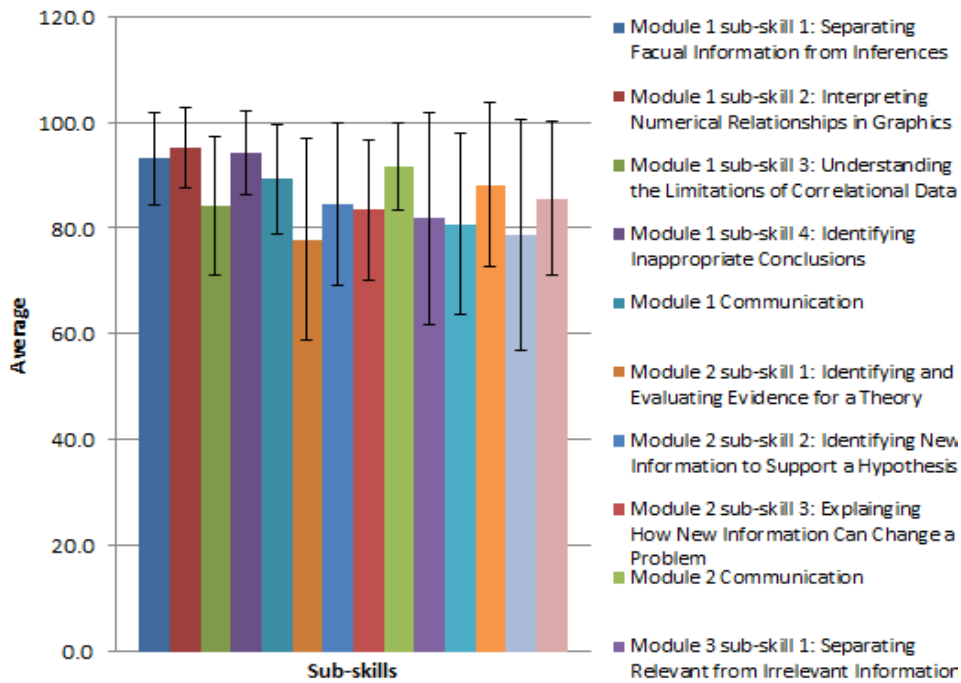


Figure 15. Average and standard deviation for the sub-skills related to modules 1-3

Average Sub-skill score including Module 4

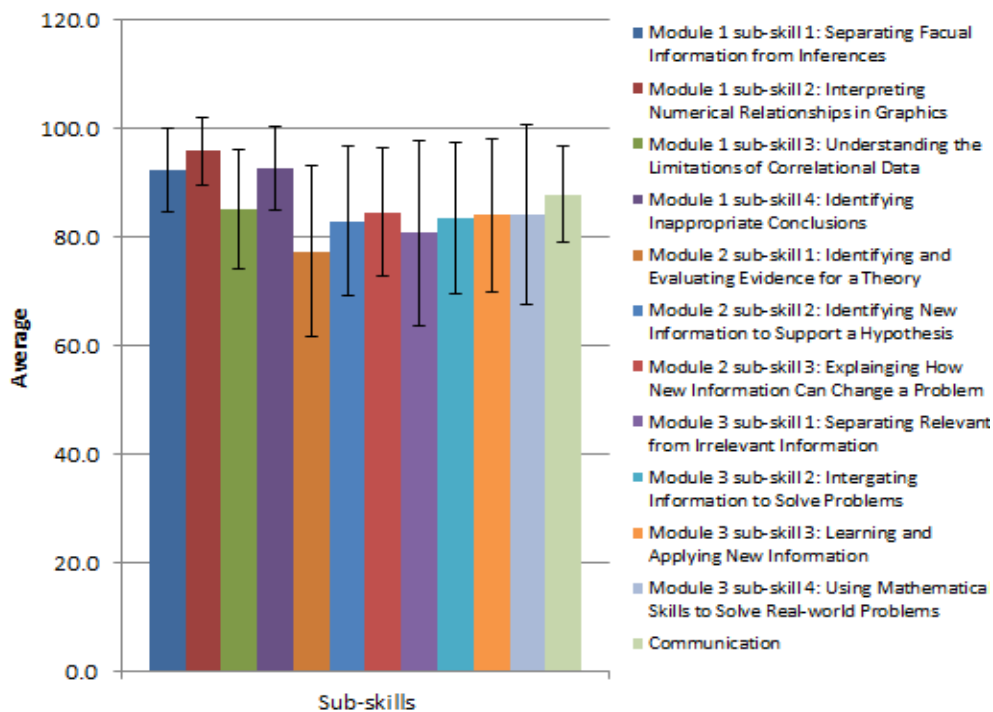


Figure 16. Average and standard deviation for the sub-skills related to modules 1-4

The rubrics were used to produce the overall course average for each student. All students participating in the study produced passing grades for the course. The class average for study participants was 88.0 with a standard deviation of 6.4. Although some students were not successful on a particular sub-skill or module, they were successful on the overall critical thinking model. This analysis is based on rubric scores produced by a single individual. The rubrics had been used previously at UTMDACC-SHP for critical thinking analysis; however, no validation studies have been conducted to ensure their validity in evaluating this skill set. Additionally, their purpose was to evaluate a single skill and not overall critical thinking abilities.

Health Science Reasoning Test results. The Health Science Reasoning Test (HSRT) was given in a pre-test / post-test format with the pre-test administered on during week 1 of the study and the post-test delivered on week 14. An intervention, the web-based critical thinking model, was implemented in the intervening weeks. The testing agency, Insight Assessment, processed all online submissions and generated reports of the results. Analysis of the numerical pre-test and post-test scores was used to test the hypothesis proposed for this study. Additional reported results, such as sub-topic scores and categories of critical thinking ability were evaluated to give further insight into the findings of this study.

Numerical value.

Overall. The overall pre-test and post-test numerical scores were used to evaluate the hypothesis proposed for this study. The change in score from pre-test to post-test was evaluated using a two-tailed, paired t-test to determine whether the integration of the multimodal model into the clinical laboratory technology programs

would provide a significant difference in critical thinking skills for these students before and after the integration. For this analysis, significance was determined using an alpha of 0.05 and a power of 0.80. This study did not produce a significant change in pre-test and post-test scores. The average pre-test score for this student population was 19.7 with a standard deviation of 5.1 and the average post-test score was 19.6 with a standard deviation of 4.9. Using a two-tailed, paired t-test, the p-value was determined to be 0.82.

Based on these results, the null hypothesis could not be rejected in favor of the alternative hypothesis, indicating that there no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. Table 18 displays the overall HSRT change results and descriptive statistics for this data set, including mode and quartile information. The quartile data indicates that the range for the pre-test was nine to 29 and for the post-test was seven to 29. However, 25% of the scores fell below 15 for the pre-test and 25% fell below 17 for the post-test. The median for both tests was 20. The data also indicated 75% of pre-test scores were below 24, and 75% of post-test scores were below 22. A box plot diagramming this data is provided in Figure 17.

Eight study participants failed to complete at least one assessment associated with the model. These students were not eliminated from the study and were included in the overall HSRT analysis. However, to evaluate whether missing an assessment contributed to the outcome of the study, a 2-tailed, paired t-test with an alpha of 0.05 was repeated for the HSRT pre-test and post-test score differences after removing values for students with missing module assessment data. Removal of these scores did

Table 18: Descriptive statistics for HSRT pre-test and post-test overall scores

	Overall Scores		
	Pre-test	Post-test	p-value
Average	19.7	19.6	0.82
Standard deviation	5.1	4.9	
Mode	20	21	
Min	9	7	
Q1	15	17	
Median	20	20	
Q3	24	22	
Max	29	29	

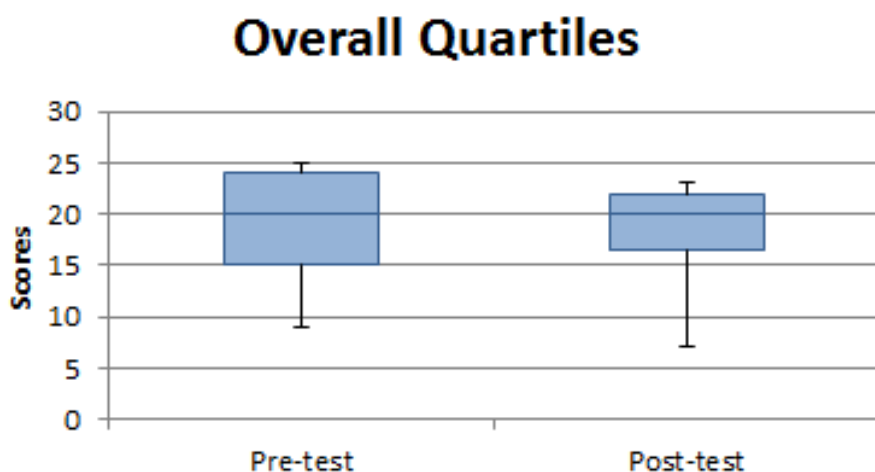


Figure 17. Quartile results for HSRT pre-test and post-test overall scores

not change the outcome of the study. The pre-test and post-test averages were calculated to be 19.8 with a standard deviation of 4.7 and 4.2, respectively and a p-value of 0.92. Data for these students was included in all other HSRT analyses.

Sub-topic. Although the sub-topic information was not used to directly evaluate the study hypothesis, it was analyzed to determine whether or not any of the specific areas were significantly changed by the implementation of the multimodal model into the clinical laboratory curriculum. Data for the five sub-topics was evaluated for pre-test

and post-test scores generated by participating students. The descriptive statistics were calculated and p-values were generated from a two-tailed, paired t-test. Using an alpha of 0.05, no significant difference was observed for any of the five sub-topic areas. The smallest p-value observed was 0.14 for the analysis section. In this section, the scores on both the pre-test and post-test ranged from 1 to 6 with a mean of 3.6 on the pre-test and mean of 3.9 on the post-test; the standard deviation was 1.3 and 1.5, respectively. For both tests, 25% of the scores fell below 3. However, for the pre-test, 75% fell below 4 and for the post-test, 50% fell below 4 and 75% fell below 5. Results for this section are displayed in Table 19 and Figure 18.

Table 19: *Descriptive statistics for HSRT pre-test and post-test sub-topic scores*

	<i>Induction</i>		
	Pre-test	Post-test	p-value
<i>Average</i>	7.0	7.0	0.92
<i>Standard deviation</i>	1.5	1.7	
<i>Mode</i>	7	8	
<i>Min</i>	4	3	
<i>Q1</i>	6	6	
<i>Median</i>	7	7	
<i>Q3</i>	8	8	
<i>Max</i>	9	10	
	<i>Deduction</i>		
	Pre-test	Post-test	p-value
<i>Average</i>	5.9	5.7	0.69
<i>Standard deviation</i>	2.5	2.3	
<i>Mode</i>	7	5	
<i>Min</i>	0	1	
<i>Q1</i>	5	4	
<i>Median</i>	6	6	
<i>Q3</i>	8	7	
<i>Max</i>	10	10	

Table 19: Continued

	Analysis		
	Pre-test	Post-test	p-value
<i>Average</i>	3.6	3.9	0.14
<i>Standard deviation</i>	1.3	1.5	
<i>Mode</i>	4	4	
<i>Min</i>	1	1	
<i>Q1</i>	3	3	
<i>Median</i>	4	4	
<i>Q3</i>	4	5	
<i>Max</i>	6	6	
	Inference		
	Pre-test	Post-test	p-value
<i>Average</i>	3.8	3.7	0.60
<i>Standard deviation</i>	1.4	1.2	
<i>Mode</i>	5	3	
<i>Min</i>	1	1	
<i>Q1</i>	3	3	
<i>Median</i>	4	4	
<i>Q3</i>	5	5	
<i>Max</i>	6	6	
	Evaluation		
	Pre-test	Post-test	p-value
<i>Average</i>	4.7	4.7	0.89
<i>Standard deviation</i>	1.0	1.3	
<i>Mode</i>	5	6	
<i>Min</i>	2	1	
<i>Q1</i>	4	4	
<i>Median</i>	5	5	
<i>Q3</i>	5	6	
<i>Max</i>	6	6	

Analysis Quartiles

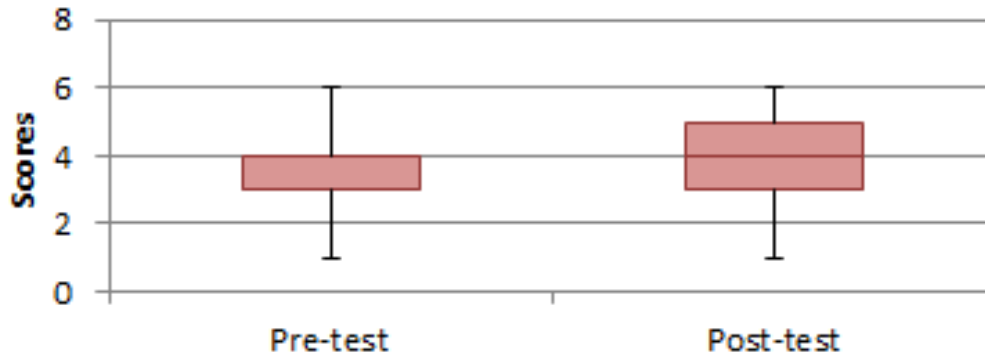


Figure 18. Quartile results for HSRT pre-test and post-test analysis scores

The mode in this section was shown to be 5 for the pre-test and 6 for the post-test. The pre-test and post-test results for induction showed that 25% of scores were below 6, 50% of scores were below 7 and 75% of scores were below 8. For evaluation, 25% of scores fell under 4 for both tests and for the pre-test 75% of scores fell below 5, while for the post-test 50% fell below 5 and 75% fell below 6. Neither of these sections showed significance with a p-value of 0.92 for the induction section and 0.89 for evaluation. Table 19 shows the descriptive statistics for both of these sections. Figure 19 displays quartile information for induction and Figure 20 displays quartile data for evaluation.

The deduction and inference sub-topics showed a slight decrease from the pre-test to the post-test. In the area of deduction, the pre-test scores were averaged to be 5.9 with a standard deviation of 2.5 and the post-test score average was 5.7 with a standard deviation of 2.3. In the area of inference, the pre-test average was calculated to be 3.8 with a standard deviation of 1.4 and the post-test average was 3.7 with a standard deviation of 1.2. For deduction, the pre-test scores ranged from 0 to 10 with a

Induction Quartiles

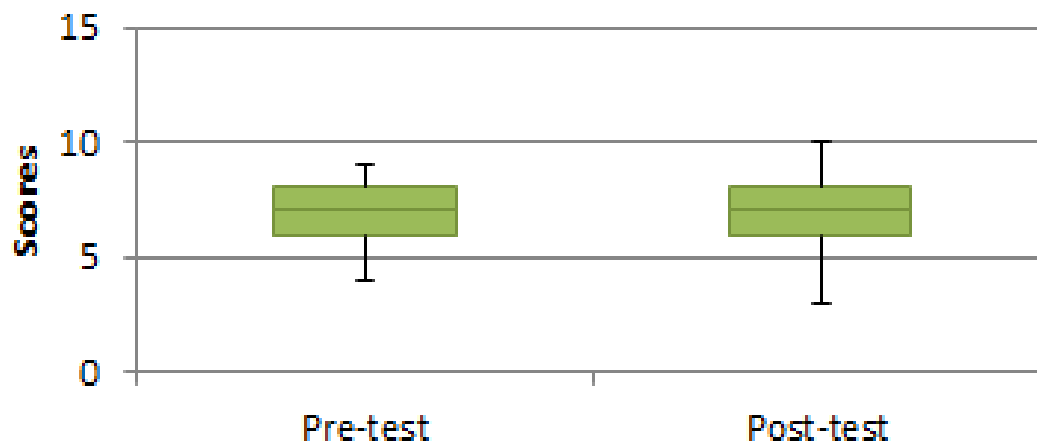


Figure 19. Quartile results for HSRT pre-test and post-test induction scores

Evaluation Quartiles

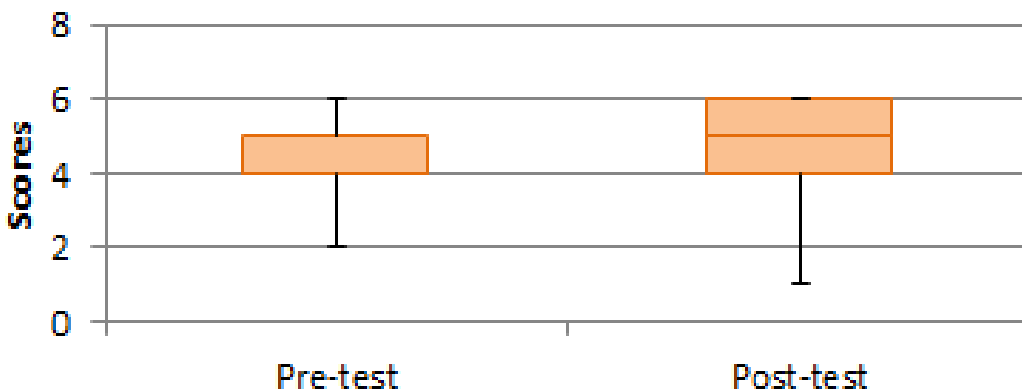


Figure 20. Descriptive statistics for HSRT pre-test and post-test evaluation scores

mode of 7 and the post-test scores ranged from 1 to 10 with a mode of 5. For inference, the pre-test and post-test scores both ranged from 1 to 6 and the pre-test mode was 5, while the post-test mode was 3. Looking at quartile data for the deduction section, 25% of scores were below 5 for the pre-test and 4 for the post-test. Fifty percent of scores fell below 6 for both and on the pre-test 75% fell below 8, while 75% fell below 7 on the

post. With the inference section, for both the pre-test and the post-test, 25% of scores were below 3, 50% were under 4 and 75% were less than 5. Figures 21 and 22 provide the quartile representations for deduction and inference, respectively, and the descriptive values can be seen in Table 19.

Deduction Quartiles

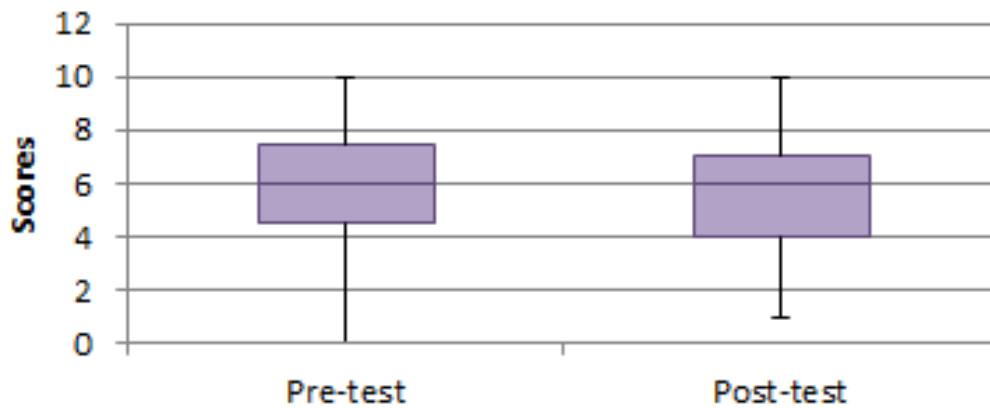


Figure 21. Quartile results for HSRT pre-test and post-test deduction scores

Inference Quartiles

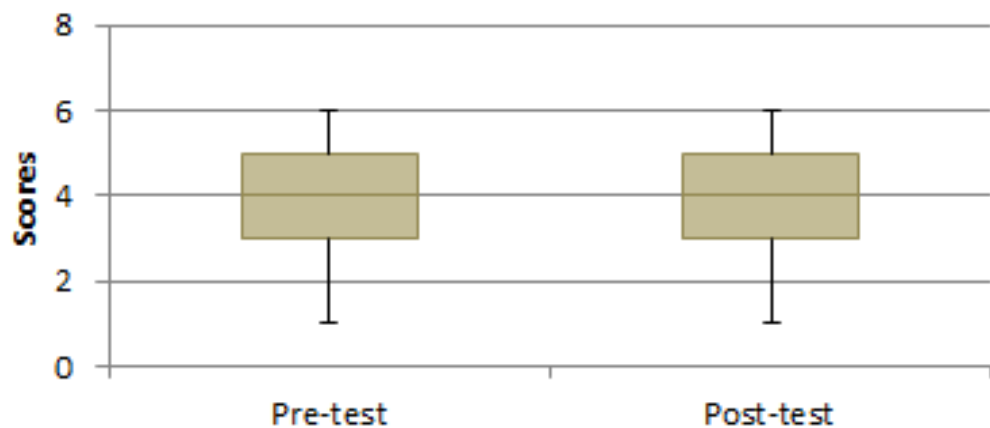
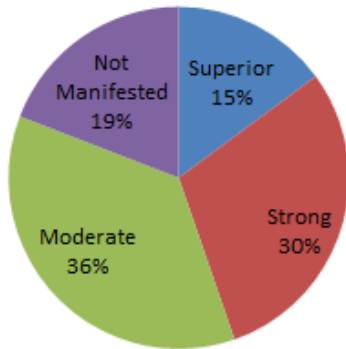


Figure 22. Quartile results for HSRT pre-test and post-test inference scores

Categorical interpretation. The overall HSRT scores can range from 0 to 33 depending on the number of questions answered correctly by the student. Scores of 26 or greater are considered superior, those between 21 and 25 are considered strong, 15 to 20 is categorized as moderate, and scores of zero to 14 are described as not manifested. Each of the sub-scores can be grouped into the same categories. For analysis, inference, and evaluation, zero to two is considered not manifested, three to four is considered weak and five or greater is considered strong. For the sub-scores of induction and deduction, zero to four is considered not manifested, five to seven is described as moderate, and eight or above is categorized as strong (Insight Assessment, 2011).

Overall. Student overall scores for the pre-test and post-test were divided into categories based on critical thinking strength provided by the testing agency. The number of students with scores in each category for the pre-test and post-test were summed. Additionally, any categorical change was noted and summed for each level of critical thinking skill achievement. For overall score results, the categories included were superior, strong, moderate, and not manifested. The category of not manifested decreased from nine students grouped in this level based on pre-test scores to six students in this level for post-test scores. The moderate category for the pre-test results included 17 students and increased to 19 for the post-test. The strong category also increased from the pre-test to post-test, changing from 14 to 15 students. There was no change in number observed for the superior category. Seven students achieved this level for the pre-test and post-test. The results for this assessment are displayed in Figure 23.

HSRT Pre-test Categories



HSRT Post-test Categories

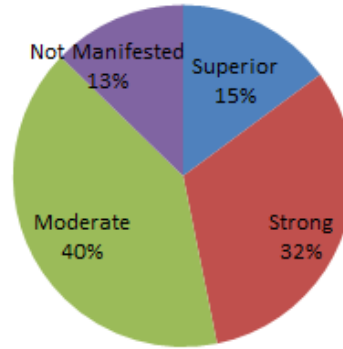


Figure 23. Percentage of students in each critical thinking category for HSRT pre-test and post-test

The number of students that stayed in the same category was assessed, along with the number that improved from a lower to higher category, as well as the number of students that dropped from a higher to a lower category. The majority of students, 30, achieved the same categorical status based on post-test results as they did in pre-test results. Ten students showed an increase and seven showed a decrease in categorical status. Those that increased or decreased, only moved up or down by one group, with the exception of one participant that increased by two categories.

For those that stayed in the same category based on pre-test and post-test scores, six were classified as superior, nine as strong, 11 as moderate, and four as not manifested. Of those participants that increased in categorical status, four moved from not manifested to moderate, four moved from moderate to strong, one moved from strong to superior, and a single student moved from not manifested to strong. The decreases in categorical level were seen in the movement of one student from superior to strong, four students from strong to moderate, and two students from moderate to not manifested. Table 20 shows the data for these results.

Table 20: *Percentage of participants with overall categorical change results for HSRT pre-test and post-test*

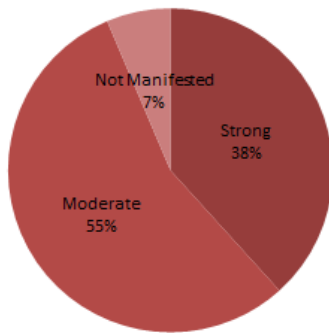
No Categorical Change			
<i>Superior</i>	<i>Strong</i>	<i>Moderate</i>	<i>Not Manifested</i>
12.77%	19.15%	23.40%	8.51%
Categorical Increase			
<i>Not Manifested to Moderate</i>	<i>Moderate to Strong</i>	<i>Strong to Superior</i>	<i>Not Manifested to Strong</i>
8.51%	8.51%	2.13%	2.13%
Categorical Decrease			
<i>Superior to Strong</i>	<i>Strong to Moderate</i>	<i>Moderate to Not Manifested</i>	
2.13%	8.51%	4.26%	

Sub-topic. Scores were provided for students for each of the following sub-topics, induction, deduction, analysis, inference, and evaluation, for the pre-test and post-test. Based on the score achieved, the student was categorized as being strong, moderate, or not manifested for each of the areas on both tests. Just as with the overall scores, the number of students with scores in each category for the pre-test and post-test were summed. Categorical changes were also noted and summed for each level of critical thinking skill achievement in each of the sub-topic areas.

Based on the pre-test results, 18 students were considered strong in the area of inductive reasoning. This number increased to 21 students on the post-test. Twenty-six students were categorized as moderate in this area based on the pre-test and this number decreased to 21 for the post-test. The number of students described as not manifested in inductive reasoning increased from three on the pre-test to five on the

post-test. Figure 24 provides a graphic representation of this information in percentages. For deductive reasoning, 12 students were categorized as strong for the pre-test and only nine fell into this category on the post-test. There were 24 students in the moderate range of deductive reasoning on the pre-test and 25 on the post-test. Eleven students were categorized as not manifested on the pre-test, and this number increased to 13 students for the post-test. The percentage of students in each of these categorical levels is for deductive reasoning is displayed in Figure 25.

Induction Pre-test Categories



Induction Post-test Categories

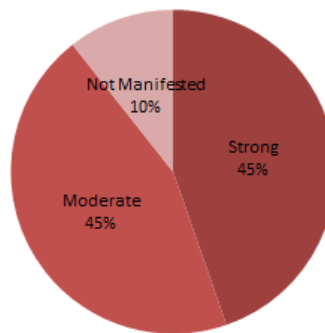
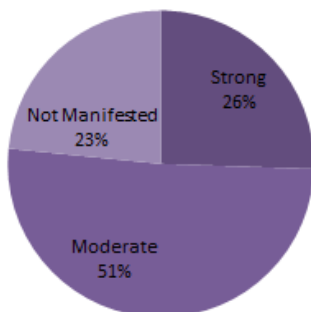


Figure 24. Percentage of students in each critical thinking category for induction sub-topic of HSRT pre-test and post-test

Deduction Pre-test Categories



Deduction Post-test Categories

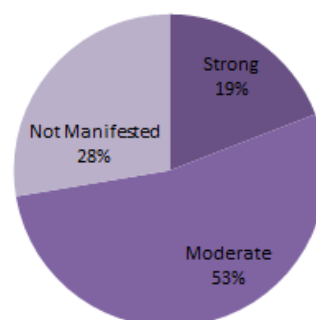


Figure 25. Percentage of students in each critical thinking category for deduction sub-topic of HSRT pre-test and post-test

Analysis provided the greatest increase in the strong category, from 11 students on the pre-test to 18 on the post-test. The moderate level included 25 students based on pre-test results, and showed a decrease to 19 for the post-test. Eleven students were categorized as not manifesting on the pre-test and 10 fell into this category on the post-test. The percentage results for pre-test and post-test results are shown in Figure 26. For the inference sub-topic, 18 students were described as strong based on pre-test results but this number decreased to 14 for the post-test. However, 11 students fell into the moderate category on the pre-test and this number increased to 26 on the post-test. Additionally, 18 students scored in the not manifested range for the pre-test; this number decreased to seven for the post-test. This information is displayed in percentages in Figure 27. Finally, for the evaluation sub-topic, 29 students were categorized as strong for the pre-test and 30 for the post-test. There were 17 in the moderate group based on pre-test results and 14 based on post test results. The number in the not manifested group increased from one to three for the pre-test and post-test, respectively. The data percentages for evaluation are shown in Figure 28.

Analysis Pre-test Categories

Analysis Post-test Categories

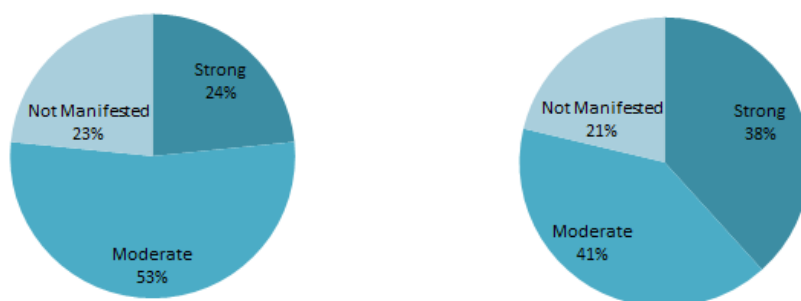
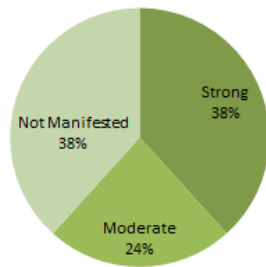


Figure 26. Percentage of students in each critical thinking category for analysis sub-topic of HSRT pre-test and post-test

Inference Pre-test Categories



Inference Post-test Categories

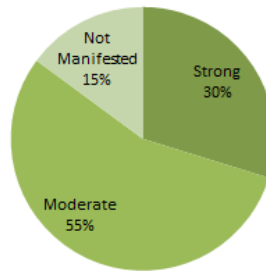
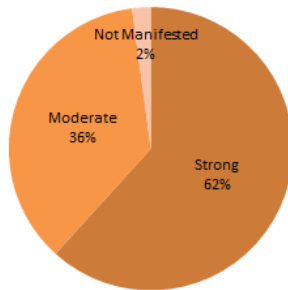


Figure 27. Percentage of students in each critical thinking category for inference sub-topic of HSRT pre-test and post-test

Evaluation Pre-test Categories



Evaluation Post-test Categories

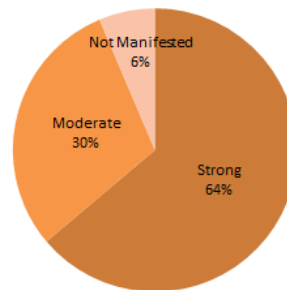


Figure 28. Percentage of students in each critical thinking category for evaluation sub-topic of HSRT pre-test and post-test

Depending on the sub-topic, a varied number of students stayed in the same category, while others increased or decreased from pre-test to post-test. In one case, a student decreased by two levels and in four cases, students increased by two levels. The majority of students stayed the same in each of the sub-topic areas. For induction, 30 students stayed the same, while nine showed some level of increase and eight showed some level of decrease. Of those that stayed the same, 14 were categorized as strong, 15 as moderate, and 1 as not manifested. Two students showed an increase from not manifested to moderate and seven showed an increase from moderate to strong. For those that decreased a category, four decreased from strong to medium and an additional four decreased from medium to not manifested. The percentage of

students at each level that stayed the same, increased, or decreased in the area of induction is shown in Table 21.

Table 21: *Percentage of participants with categorical change results for each sub-topic of the HSRT pre-test and post-test*

No Categorical Change			
	<i>Strong</i>	<i>Moderate</i>	<i>Not Manifested</i>
Induction	29.79%	31.91%	2.13%
Deduction	12.77%	34.04%	17.02%
Analysis	17.02%	23.40%	10.64%
Inference	12.77%	21.28%	6.38%
Evaluation	53.19%	19.15%	0.00%
Categorical Increase			
	<i>Not Manifested to Moderate</i>	<i>Moderate to Strong</i>	<i>Not Manifested to Strong</i>
Induction	4.26%	14.89%	0.00%
Deduction	6.38%	6.38%	0.00%
Analysis	10.64%	19.15%	2.13%
Inference	10.64%	10.64%	6.38%
Evaluation	2.13%	10.64%	0.00%
Categorical Decrease			
	<i>Strong to Moderate</i>	<i>Moderate to Not Manifested</i>	<i>Strong to Not Manifested</i>
Induction	14.81%	14.81%	0.00%
Deduction	22.22%	18.52%	0.00%
Analysis	11.11%	18.52%	0.00%
Inference	40.74%	11.11%	3.70%
Evaluation	14.81%	11.11%	0.00%

In the area of deduction, 30 students again did not change categories. However, only six were shown in the strong category, while 16 were categorized as moderate and eight as not manifested. For this sub-topic, six increased a level from pre-test to post-test and 11 decreased. Of the six that increased, there were three that went from not manifested to moderate and another three that went from moderate to strong. For the

11 that decreased, six decreased from strong to moderate and five from moderate to not manifested. Table 21 provides the percentages for students that stayed the same level, increased a level, or decreased a level in the area of deduction.

For analysis, 24 total students did not increase or decrease in categorical level. Eight of these students remained strong for both pre-test and post-test results, 11 stayed at the moderate classification, and five remained in the not manifested level. For this sub-topic, 15 students increased by at least one category, with five increasing from not manifested to moderate, nine increasing from moderate to strong, and one improving by two categories from not manifested to strong. For the analysis sub-topic, eight students showed a decrease in level. Of these students, three decreased from strong to moderate and five decreased from moderate to not manifested. The analysis section showed the greatest number of students that increased by at least one category. The percentage of students with and without change in ability to analyze data is described in Table 21.

The inference section had the smallest number of students that did not change categories at 19 and the evaluation section had the largest number of students that did not change categories at 34. For inference, six students remaining in the same category were categorized as strong for both the pre-test and post-test, while 10 were categorized as moderate, and three did not manifest. For the evaluation sub-section, 25 students remained in the strong category for both the pre-test and post-test, nine in moderate, and no students failed to remain at the not manifested level. For the inference sub-topic, 13 students increased levels and 15 decreased. Of those increasing, five moved from not manifested to moderate and five moved from moderate

to strong, while three moved two groups from not manifested to strong. For those that decreased, eleven went from strong to moderate and three shifted from moderate to not manifested, while one dropped two levels from strong to not manifested. In the area of evaluation, six students showed an increase, one from not manifested to moderate and five from moderate to strong. Additionally, seven showed a decrease with four moving from strong to moderate and the remaining three decreasing from moderate to not manifested. Table 21 provides the percentages for number of students relating to each of the categories and categorical movements for inference and evaluation.

Time on test. In an evaluation of the time spent on the pre-test compared to the time spend on the post-test, significantly more time was spent on the pre-test based on a 2-tailed, paired t-test with an alpha of 0.05. This calculation produced a p-value of 0.000. The average amount of time spent on the pre-test was 44 minutes with a standard deviation of 7.3 minutes and the average amount of time spent on the post-test was 36 minutes with a standard deviation of 8.5.

Regression models. In order to evaluate the relationship between independent variables related to the participants and the overall outcome of the study, standard linear regression model was created in SPSS, version 22 (IBM Corp., 2013). The independent variables entered into this model were program, primary language, comfort level with English, GPA, age, ethnicity, gender, work experience, level of education, Sakai usage of reference materials, and the difference in amount spent on the pre-test and post-test. Missing values for GPA and age were replaced with the average value for each variable. The nine missing GPA values were replaced with 3.5 and the two missing age values were replaced with 27. All independent variables were entered

model for standard linear regression. Additionally, the variables were evaluated independently for significant contribution.

In order to perform this analysis, the categorical variables had to be recoded to integers. For the program, ethnicity, gender, and English as a primary language, an auto recode command was used because there was no preference on value or the variables were dichotomous. For comfort level with English, educational experience, and work experience, the variables were manually recoded, assigning the lowest value to lowest category. Table 22 displays the coding for all categorical variables. Age, GPA, Sakai usage, and change in time spent on test were already numerical in nature and therefore did not require coding. Sakai usage value corresponded to the amount of reference material used by each participant and the time change variable was calculated as the difference for the post-test minutes minus the pre-test minutes.

The overall regression model was significant at an alpha level of 0.05. This model produced a p-value of 0.009, indicating 99.1% confidence that the relationship exists in the population. Additionally, 47.5% of the variance in the HSRT change score is explained by the linear combination of variables in this model. When considering the number of variables in the model and sample size, the amount of explained variance is reduced to 31.0%, as represented by the adjusted R square value. A Durbin-Watson value of 2.146 confirms the assumption of a regression model that the error deviations for the variables in the model are uncorrelated. For this model, educational experience (p-value 0.001), time change on the test (p-value 0.050), Sakai usage (p-value 0.041), and GPA (p-value 0.045) are significant. Educational experience and Sakai usage are inversely related to the HSRT score change variable with coefficients of -1.197 and

Table 22: *Categorical variable coding for regression analysis*

Variable	Type of Recode	Recoded Variables				
Program	Auto	CGT = 1	CLS = 2	CT = 3	HT = 4	MGT = 5
Ethnicity	Auto	Asian, Asian American, Pacific Islander = 1	Black, African American = 2	Hispanic, Latino, Mexican American = 3	White, Caucasian, Anglo American = 4	
Gender	Auto	Female = 1	Male = 2			
Primary language	Auto	No = 1	Yes = 2			
Comfort level with English	Manual	Moderate = 1	Good = 2	Excellent = 3		
Educational Experience	Manual	Attended a junior or community college = 1	Attended a 4-year university or college = 2	Completed a bachelor's degree = 3		
Work Experience	Manual	I have never worked in a laboratory environment = 1	I have worked in a laboratory environment for less than 2 years = 2	I have worked in a laboratory environment for 2-5 years = 3	I have worked in a laboratory environment for greater than 5 years = 4	

-0.334, respectively. The difference in the amount of time spent on the pre-test compared to that spent on the post-test and reported GPA value indicated positive relationships with coefficients of 0.109 and 0.289, respectively. All other variables remained insignificant at an alpha level of 0.05. Table 23 includes the model, model summary and coefficient values, with significance levels produced by SPSS (IBM Corp., 2013).

Table 23: *Model, model summary and variable coefficients, with significance levels (N=47)*

Variables Entered / Removed ^a					
Model	Variables Entered	Variables Removed	Method		
1	SMEAN(Age)		Enter		
	Time change				
	Gender				
	Primary language				
	Program				
	SMEAN(GPA)				
	Educational experience				
	Work experience				
	Sakai usage				
	Ethnicity				
	Comfort with English ^b				
a. Dependent Variable: HSRT score change					
b. All requested variables entered.					
Model Summary					
Model	R	R Square	Adjusted R Square	Standard Error of the Estimate	Durbin-Watson
1	.689 ^a	0.475	0.31	2.6	2.146
a. Predictors: (Constant), SMEAN(Age), Time change, Gender, Primary language, Program, SMEAN(GPA), Educational experience, Work experience, Sakai usage, Ethnicity, Comfort with English					
b. Dependent Variable: HSRT score change					
ANOVA ^a					
	Sum of Squares	Degrees of Freedom	Mean Square	F-statistic	Significance
Regression	213.817	11	19.438	2.875	0.009 ^b
Residual	236.651	35	6.761		
Total	450.468	46			
a. Dependent Variable: HSRT score change					
b. Predictors: (Constant), SMEAN(Age), Time change, Gender, Primary language, Program, SMEAN(GPA), Educational experience, Work experience, Sakai usage, Ethnicity, Comfort with English					

Table 23: *Continued*

Coefficients ^a					
	Unstandardized Coefficients		Standardized Coefficients	t-statistic	Significant
	B	Standard Error	Beta		
(Constant)	0.539	5.082		0.106	0.916
Program	0.306	0.251	0.165	1.217	0.232
Primary language	-0.971	1.099	-0.151	-0.884	0.383
Ethnicity	-0.343	0.416	-0.136	-0.827	0.414
Gender	-0.359	0.847	-0.057	-0.424	0.674
Time change	0.109	0.054	0.259	2.059	0.05
Comfort with English ^b	-1.986	0.858	-0.216	-1.149	0.258
Educational experience	-1.917	0.551	-0.475	-3.482	0.001
Work experience	0.071	0.518	0.019	0.136	0.893
Sakai usage	-0.005	0.003	-0.334	-2.123	0.041
SMEAN(GPA)	2.447	1.176	0.289	2.08	0.045
a. Dependent Variable: HSRT score change					

Educational experience. Based on the total number of participants included in the study, 33 noted that they attended a junior or community college prior to enrolling at UTMDACC-SHP. Fourteen attended a four-year university or completed a bachelor's degree. Using a two-tailed t-test with a significance level of 0.05, as expected, there was a significant difference (0.002) in the HSRT score change between these two groups. The average score change for students having previously attended a junior or community college was 0.8 with a standard deviation of 3.2 compared to -0.2.2 with a standard deviation of 1.6 for those having attended a four-year university or previously completed a bachelor's degree. When evaluating the pre-test HSRT score and post-

test score individually for both groups, the pre-test score was significantly higher (0.04) for students having attended a four-year university or having received a bachelor's degree as compared to those from a junior or community college; however, the post-test score was not significantly different (0.88). No student that reported attending a four-year university or having a bachelor's degree showed improvement on HSRT. The complete list of averages and standard deviations for comparisons of educational experience is shown in Table 24.

Table 24: *Educational experience and HSRT scores comparisons*

	Pre-test		Post-test		Score change	
	Junior or community college (N=33)	4-year university or bachelor's degree (N=14)	Junior or community college (N=33)	4-year university or bachelor's degree (N=14)	Junior or community college (N=33)	4-year university or bachelor's degree (N=14)
Average	18.8	22	19.5	19.8	0.8	-2.2
Standard deviation	5.5	3.1	5.6	3.2	3.2	1.6
p-value	0.04		0.88		0.002	

Chapter Five - Discussion

Overview

The purpose of this study was to investigate the difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. The study was designed to address three specific aims related to a single hypothesis. The aims for this study were to design a multimodal teaching model to enhance critical thinking skills in clinical laboratory technology students, implement that model into the clinical laboratory technology student curriculum, and evaluate the success that model in improving critical thinking skills of students in clinical laboratory technology programs. The study's null hypothesis stated that there is no significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. The alternative hypothesis specified significant difference in critical thinking skills for clinical laboratory students before and after the integration of a multimodal model targeting this skill set into the curriculum. Improvement of this skill set in the educational setting would equip graduates with the level of critical thinking skills needed for entry into the professional work environment.

Summary of Findings

The three aims of this study were addressed through the design, implementation, and assessment of a web-based model centered on the enhancement of critical thinking

skills. A quasi-experimental, pre-test / post-test study was conducted with a single group including a convenient sample of students in clinical laboratory technology programs at the University of Texas M.D. Anderson's School of Health Professions (UTMDACC-SHP). The study results did not show a difference between the scores achieved on the post-test as compared to the pre-test, with the critical thinking model serving as an intervention. Therefore, the alternative hypothesis was rejected in favor of the null hypothesis.

Based on previous studies (Huhn, Black, Jensen, & Deutsch, 2011; Sullivan-Mann, Perron, & Fellner, 2009) using the Health Science Reasoning Test (HSRT) in a pre-test / post-test format, this current study sample size of 47 was large enough to achieve statistically significant results. However, due to the average score change of - 0.1 point and standard deviation of 3.1 points achieved for this study, significant results were not observed ($p=0.82$). The studies cited above resulted in a score change for 1.5 points and standard deviation of approximately 3.5. The proposed power for this study was set at 0.8 but the power attained for this study was only approximately 4%. Although the overall change results used to evaluate the hypothesis showed no significant difference in student critical thinking skills before and after model integration, further investigation of relationships between demographic and usage variables were conducted, along with observations related to critical thinking categorical groups, HSRT sub-topic scores, and rubric scores.

A regression model including prior education experience, time spent on the HSRT pre-test as compared to the post-test, GPA, usage of Sakai resources, program of enrollment, gender, ethnicity, age, primary language, comfort with the English

language, and work experience was significant in predicting the pre-test / post-test HSRT change score. Four independent variables, prior educational experience, Sakai usage, change in time spent on the HSRT assessments, and GPA indicated a significant relationship with the change score. Understanding the interaction with these variables and the outcome variable provided additional insight into the population that would benefit most from this model and factors that might have contributed to the overall study results. Although this study was designed to evaluate critical thinking as a whole, results of the sub-topics and module rubric scores were examined to ascertain additional information about the model design and assessment instruments utilized.

Interpretation of Findings

As the model was designed, implemented, and assessed for this study, it was not able to show an improvement in critical thinking skill for the students included in the study. Standard linear regression found an inverse relationship between level of past educational experience for a student and the HSRT change score. The higher the level of education, the smaller the value for the pre-test and post-test change score. Students that attended a junior or community college prior to enrolling at UTMDACC-SHP showed significantly more improvement in HSRT score change, as compared to those that previously attended a four-year university or received a bachelor's degree. Upon further investigation, the post-test scores for these two groups were not significantly different; however, the pre-test score was significantly higher for the students having attended a four-year university or received a bachelor's degree as compared to those from junior or community colleges. On average, students from junior and community colleges showed improvement in their post-test scores as compared to their pre-test

scores; however this was not significant. Students having attended a four-year university or having obtained a bachelor's degree showed a decrease in score for the post-test compared to the pre-test.

Because the pre-test score was significantly lower for students from junior or community colleges, this group of students had more room for improvement. Those coming from four-year universities and those already having a bachelor's degree started with an average pre-test score that was significantly higher than the other group. The lack of improvement in this group could be attributed to a ceiling effect. Post-hoc analysis indicated that the pre-test HSRT scores were negatively correlated with the HSRT score change values. Therefore, the higher the pre-test score, the less the observed HSRT score change. For this study, no student in the four-year university / bachelor's degree group showed any improvement in HSRT post-test score as compared to their pre-test score.

The reduction in post-test scores, compared to pre-test scores may have occurred as a result of regression to the mean. This bias suggests that if a value is extremely high on one assessment that it will migrate towards the mean on the next or vice versa. However, extremely low scores would also move in this direction because extreme test scores are more likely to be affected by error. The test re-test reliability for the HSRT would provide more information on this concept. However, this value is not published. The testing agency does state that students retaking this test, without any intervention, should score within one point of their original score if retaken within a two week period (Insight Assessment, 2013). This would not fully explain an average score decrease of 2.2 for the four-year university / bachelor's degree group.

Based on the standard regression analysis, GPA was positively correlated with the HSRT score change. The coefficient of 2.447 indicates that with every point increase in GPA score, the HSRT post-test score will increase by 2.447 points in comparison to the pre-test score. The relationship between GPA and critical thinking assessment tools is commonly evaluated in validity studies but typically conducted in a single testing session (Facione, Facione, & Giancarlo, 2000), as opposed to the comparison with a pre-test / post-test score change. For this study, no relationship was observed in a post-hoc analysis between the pre-test HSRT score and student GPA. The GPA range for this student population was limited due to admission criteria for the clinical laboratory technology programs at UTMDACC-SHP. As a result, there was no representation for GPAs below 2.5 and the average value observed for this study was 3.5. Additionally, these scores were self-reported and several students noted the uncertainty of their current GPA standing.

The regression model also found a direct relationship between the difference in the amount of time a student spent on the assessment tests and the change in overall HSRT score. Students with a smaller time change value showed less improvement on the HSRT assessment. Therefore, the more time the student spent on the post-test as compared to the pre-test, the more likely the HSRT score change would increase. When comparing the pre-test and post-test scores for the entire group, students spent significantly less time on the post-test. The time change variable was only significant for the group as a whole and not for junior or community college students compared to the four-year university and bachelor degreed students.

There are a number of factors that could contribute to the reduced time spent on the post-test. The same testing instrument was used for the pre-test and post-test; however, the re-testing period was separated by 13-weeks; therefore, any contribution from memory bias should be low. It is more likely that this time difference can be attributed to cognitive fatigue. The pre-test was taken on the first week of the semester and the post-test was taken on the week prior to the final week of the semester. This post-test date coincided with preparation for final exams in other programmatic courses. Additionally, there was no incentive for completion or success since the pre-test and post-test assessments did not count towards the students' course grades.

The modules included in the critical thinking model did contribute to the students' course grades and aside from the cumulative final module, the module grades decreased as the semester progressed. This phenomenon could support the idea of cognitive fatigue or be linked with the student's ability to master the content. The final, cumulative module was an exception as it produced the second highest average score. This module was due the week before the post-test. It differed from the other three modules in that the students were allowed two instead of only one week for completion. It is possible that the time allowed for each module needs to be further investigated. Although not tracked, it was observed that some students waited until the last minute to begin the assessment, others opened the document early. There is no way of monitoring the amount of time each student spent on each assessment.

Success on the modules did not correspond with Sakai visits. Based on Sakai statistics, students visited the Sakai site the most in October, followed by November, September, and December. Only a single assessment for the final cumulative module

was due in December. For October and November, six assessments were required and seven in September. The number of visits to Sakai only explains the number of times the student entered the site and not the individual links that were accessed. Therefore, a student that entered the site once in a day and reviewed multiple documents would only count as a single entry where as a student that entered the site multiple times in one day and only viewed a single entry would count for multiple visits. This statistic is not extremely accurate in evaluating usage of the model components.

Usage of Sakai reference material was inversely related to the HSRT score change. The result suggested that for every additional reference accessed, the score change would decrease by 0.005 points. Although this variable is more accurate than visits, it only monitored the number of times a student visited the reference area within Sakai. It did not account for outside access or the amount of time each document was opened. Because links were provided to the references that redirected students outside the system, it is unknown whether the students saved those documents or printed them for additional review. Also, Sakai does not track the amount of time each document is reviewed; only that it was opened. Therefore, it is possible that this variable did not accurately account for usage of the reference material.

Lack of effort may explain a portion of the results observed in the category containing the lowest score range, not manifested. The testing agency attributed students falling into this category to “insufficient test-taker effort, cognitive fatigue, or possible reading and language issues” (Insight Assessment, 2013). For the overall HSRT results, the percentage of students in this category decreased from 19% for the pre-test to 13% for the post-test. Although statistical analyses were not conducted for

the categorical results specifically, the lowest HSRT scores fell into the not manifested category; and statistical analysis of the numerical results indicated that the less time the student spent on the assessment, the less improvement they showed in critical thinking ability. Cognitive fatigue and reading skills were not specifically measured.

Though 36% of study participants reported that English was not their primary language and 11% reported only a moderate comfort level with English, primary language and comfort with English were not found to significantly relate to the score change. However, this data was collected at the beginning of the study and not re-evaluated as the semester progressed. It is possible that students with limited English skills became more familiar with the language as the semester progressed. In evaluation of the sub-topic data, the percentage of students in the not manifested category varied by topic, from 2% to 38%. If this percentage was attributed to language, less variability would be expected among the topics and with language. Additionally, this value did not decrease for every sub-topic as would be expected for language improvements.

It is also possible that some students fell into the not manifested category as a result of poor critical thinking ability and improved as the semester progressed. Although the numerical scores did not show a significant difference in pre-test and post-test scores for the group as a whole, the categorical scores showed the decrease in students described as not manifested and an increase in the percentage falling into the moderate and strong groups, while the percentage in superior remained the same. These results suggest an improvement in critical thinking ability.

To better understand the areas of the model that were most successful, the sub-topics of critical thinking covered by the HSRT including induction, deduction, analysis, inference, and evaluation, were evaluated, along with the module and sub-skill results generated from rubric analyses. The HSRT assessment was developed in accordance with the 1990 Delphi Report, and the critical thinking definition used for model development in this study replicated the skills and sub-skills described by Tennessee Tech University (TTU) (American Philosophical Association, 1990; Tennessee Tech University, 2008). Skills from the Delphi Report were aligned with the UTMDACC-SHP definition and presented in Table 1. Sub-skills aligned between the Delphi Report and TTU were included in Table 4. Although the HSRT was developed in accordance with the Delphi Report, the sub-topics are not exactly the same. The Delphi Report and the HSRT overlap in the areas of analysis, inference, and evaluation. Based on alignment between the Delphi Report and critical thinking skills for this study, analysis and inference were most represented in the study model, followed by evaluation.

Of all sub-topics, inference corresponded with the lowest average rubric score. The inference sub-topic closely aligns with demonstrating creativity and resourcefulness in learning and problem solving found in the UTMDACC-SHP definition. Additionally, three sub-skills targeted by this study, identifying and evaluating evidence for a theory, identifying new information to support a hypothesis, and integrating information to solve problems, aligned with inference. The rubric scores on these sub-skills were three of the four lowest scores in comparison of all 12 included in the model. It is possible that the rubrics need to be adjusted to better evaluate this skill set or that this students suffered from cognitive fatigue by the time they reached this third module. Post-hoc analysis

revealed no correlation between success on the model sub-topics targeting inference and the change in pre-test and post-test HSRT scores for the inference section.

Therefore it is more likely that this sub-topic needs to be better targeted by the model.

Evaluation of the numerical HSRT data for the inference sub-topic showed an average decrease for post-test scores as compared to pre-test scores. The categorical HSRT data for the inference sub-topic revealed a decrease in the not manifested group but also a decrease in the percentage of students in the strong category. Further, faculty evaluations concerning materials and assessments produced the lowest results for the sub-skills related to inference. Comments from these evaluations were addressed by the PI prior to implementation of the model. However, the model was not reevaluated after modifications were made. Due to the low performance by students for this topic, more adjustments may be needed to ensure that the content in the Powerpoint presentations introducing these sub-skills are clear and useful.

The evaluation sub-topic was included in the Delphi Report and represented on the HSRT assessment. It did not correlate with a complete module but did find alignment with a sub-skill included in this model, explaining how new information can change a problem. Based on student performance for all sub-skills included in the model, the performance on this sub-skill fell near the average. Like inference, the numerical HSRT scores showed very little difference between the pre-test and post-test values and the categorical scores showed an increase in not manifested, along with an increase in the percentage of students in the strong category. Comparison of the evaluation sub-topic to all other sub-topics indicates that there was the least room for improvement in this area. Only two percent of students were initially categorized as not

manifested while 62% were described as strong. Due to the success of this sub-topic on the pre-test, the lack of improvement in this area may be attributed to the ceiling effect.

Although not significant, the analysis sub-topic produced the most improved results for the post-test as compared to the pre-test. Additionally, the percentage of students falling into the not manifested group dropped while the percentage of students in the strong category increased by 14%. This sub-topic was represented by three sub-skills in the critical thinking model. Based on rubric scores, students did well on two of the three. They did well on identifying inappropriate conclusions and understanding the limitations of correlational data but struggled with separating relevant from irrelevant information. However, no correlation was shown between the individual sub-skill aligned with the analysis sub-topic and the change in analysis score from HSRT pre-test to post-test. Because students had varied success with the sub-skills, it is possible that the rubrics used for scoring need to be modified to produce more reliable values.

Overall, the poorest performance was observed in relation to the deduction sub-topic. The additional two sub-topics represented on the HSRT assessment, induction and deduction, were not included in the list of skills summarized by the Delphi Report and were, therefore, not aligned with the critical thinking definition adopted by this study. None of the sub-skills included in the model were specifically designed to target these sub-topics. Based on average numerical HSRT results, there was little change for induction but a decrease for the average post-test score for deduction. The categorical results showed an increase in the percentage of students described as not manifested for both induction and deduction. Induction produced an increase in the strong group but deduction showed a decrease. Additional sub-skills may need to be added to the

model or current sub-skills may need to be adjusted to specifically target these sub-topic areas.

This model was constructed to target critical thinking overall as defined as the ability to effectively evaluate and interpret data, apply existing knowledge to solve problems in new situations, demonstrate creativity and resourcefulness in learning and problem solving, and effectively and persuasively communicate findings. Although there are a variety of critical thinking definitions in the literature, the one chosen for this study was aligned well with Anderson's Taxonomy and the skill set presented in the 1990 Delphi Report (Anderson & Krathwohl, 2001; American Philosophical Association, 1990). However, evaluation of the individual HSRT topics suggest that more emphasis needs to be placed on deduction; and improvements are most needed in the area of inference.

Concerning the overall format of the model, faculty members evaluated the model design and structure, topic of lung cancer used for case studies, amount of reference material included, level of reference material, level of assessment, ease of use overall, use of Sakai as the platform, the online delivery method, instructor presence, and the feedback provided to students. The areas receiving the lowest scores were amount of reference material, delivery method, and instructor presence. This evaluation was conducted prior to implementation and most comments and concerns were addressed by the PI. However, the amount of reference material was not decreased and the online delivery method was not altered.

Although the faculty members provided a lower ranking for the amount of reference material, they ranked the level of material high. The third module targeting

creativity in learning and problem solving contained the most documents, followed by module 1 focusing on effectively evaluating and interpreting data. Module 2, applying existing knowledge to solve problems in new situations contained the least reference links. However, the number does not necessarily reflect the length or time involvement of each. Module 4, the final summation module did not contain any new material and the students performed better on this one than module 2 or 3. Additionally, students were allowed two weeks to complete module 4 as opposed to one week for the others. The improvement could be attributed to the extra practice with the skill set or the additional time allotted. It may be necessary to revisit the amount of reference material supplied and the amount of time required to for module completion.

Another concern voiced by the evaluators was the delivery method. Although faculty members provided a lower ranking for the online delivery method, they provided a high ranking for the use of Sakai as the delivery platform. Because of the nature of the study, the online and asynchronous format was not altered prior to implementation. Student surveys completed at the end of the course ranked the online format favorably. Although the model was online and asynchronous, students were provided with options for real-time and asynchronous interactions with each other and the instructor, including discussion boards, live chat rooms, and email. Neither the discussion boards nor chat rooms were used by the students for topic discussion. Emails between the instructor and students typically concerned only general course questions, emails and direct conversations between students were not monitored. In the future, to ensure that discussions are taking place and to track students that are mastering the material as opposed to those that are struggling, discussion board posts could be mandated.

Discussion boards use, opposed to live chat rooms would still maintain the asynchronous nature of the model.

Faculty evaluations also produced a lower ranking for instructor presence. This topic was addressed prior to model implementation through the addition of videos commentary, text reminders, and positive feedback received upon assessment submission. No follow up evaluation was provided to ensure improvement in this area. The student survey did not provide a question related to this topic.

Context of Findings

The critical thinking model developed for this study incorporated constructs related to the Cognitive Flexibility Theory, such as scaffolding, anchored instruction, case-based learning, and multimodality. Studies found in the literature utilizing this theory did not empirically evaluating critical thinking ability related to its use but provided some insight into successful model design and implantation. Faculty observations pertaining to a course implemented at the University of Wisconsin shares some similarities with observations related to student usage in this study (Siegel, et al., 2000). The course developed at the University of Wisconsin was web-based and utilized case studies and problem scenarios. Unlike this study, it was not designed to improve critical thinking skills; and this skill set was not measured. Additionally, this course was not in the area of allied health. However, there were many similarities in the use of the Cognitive Flexibility Theory and related constructs.

The content was structured using an online platform and the learning outcomes were defined, along with related perspectives, themes, and concepts. Cases were used to illustrate the concepts and an online interface assisted in guiding users through the

model content. Students were asked to solve problems related to the cases and used electronic resources as references. The course was implemented over a single semester. However, the content was delivered in a synchronous manner and incorporated a small group social aspect.

A satisfaction survey completed by students at the end of the course suggested the need for better instruction and additional resources. The faculty found that students preferred multiple paths to reach the concept, student learning centered on the case as opposed to proceeding from concept to concept, and students needed to be reminded to use additional resources. Although students in this study provided positive responses to the content included and online format, faculty observations resembled those found for the University of Wisconsin course. Students had to be reminded of the course focus on critical thinking skills, as opposed to case study concepts, and some needed additional guidance related to the resources provided.

Additional studies found in the literature shared some overlap with constructs related to the Cognitive Flexibility Theory and those utilized in this study but were not designed using this theory (Beadling & Vossler, 2001; Kaddoura, 2011; Derwin, 2009; Yang, Newby, & Bill, 2005). These studies showed some success with incorporation of similar design and implementation strategies. A study in the area of clinical laboratory science utilized the adaptive release of information related to a case study by supplying the students with new information related to the case over a three to five week period. A single case study was incorporated over a short time period, unlike the multiple case studies and other information sources set for adaptive release over a 14-week period for this study. Students were required to analyze data and submit written and oral

responses to be graded by a rubric. Although no critical thinking assessments were used, this method was reported to have positive results for students in this discipline (Beadling & Vossler, 2001).

A study in the area of nursing used the California Critical Thinking Skills Test (CCTST) to evaluate the benefit of case-based learning over standard didactic format. Although the HSRT was not utilized in this study, it was designed to target the same areas of critical thinking as the CCTST. The Kaddoura (2011) study showed that case-based learned improved critical thinking skills over didactic methodologies in nursing students. This study was unable to show a significant improvement in critical thinking skills for clinical laboratory students but did not aim to compare teaching formats.

This study incorporated online instruction with asynchronous learning and did not include a social aspect but aimed to include adequate teacher presence. The literature search produced studies indicating no significant difference in face-to-face versus online format for improving critical thinking skills (Clark, 2002; Pyre, 1997; Derwin, 2009). However, none of them were conducted in the clinical laboratory setting; and only Derwin (2009) used a critical thinking assessment test. Like this study, the pre-test was taken at the beginning of the semester and the post-test was taken at the end of the semester. However a critical thinking intervention was not utilized and the study consisted of adult learners. Findings from comparisons of the CCTST scores indicated that there was not improvement in critical thinking abilities for either group and that no difference was observed between face-to-face and online instruction (Derwin, 2009). This study supports the use of online instruction as a valid teaching format but offers no basis for critical thinking enhancement.

Two studies on the use of asynchronous learning found it beneficial in improving critical thinking skills; however, the conclusions were based on observation and students surveys (Chang, 2002; Yang, Newby, & Bill, 2005). In both cases, asynchronous discussion boards were utilized for student discussion and proved to be useful in the observed improvement of critical thinking ability. One study incorporated Socratic questioning and evaluated the quality of discussion board responses (Yang, Newby, & Bill, 2005). In this study, discussion boards were offered to students as a platform for content discussion; but their use was not mandated. The instructor set up discussion threads by sub-skill topic but did not pose questions to stimulate conversation amongst students. No content discussion occurred during the course of this class. The asynchronous nature of this course might be improved through the use of discussion boards. Instead of posting topics and waiting for student participation. The instructor may need to pose questions and motivate student response through grading.

The majority of critical thinking courses incorporate a social aspect in some way. However, a study by Wang, et al. (2009) described the beneficial use of an online course for enhancing critical thinking without a social aspect. Likewise, this course did not require a social aspect. Students were provided with the discussion boards, along with chat rooms and email. Chat rooms were open to students for optional use; however, like the discussion boards, these were not used. Email was available for communication via student to student or student to instructor. The message could be sent out to an individual or to the entire roster. This was the most used mode of communication but typically only involved general questions presented by the students to the instructor. However, student to student emails were not monitored and because

this online course occurred in a university setting, face-to-face student discussions were possible but also not monitored.

It is clear that students did not utilize the modes of communication provided within the model but it is unclear as to whether outside communication methods were used. It is possible that some students did incorporate a social aspect to the course but it is unknown as to how many or to what degree. It is also possible that students did not utilize the social options because they preferred to work independently. A student response on the survey conducted at the end of this course stated that he enjoyed working independently and overall students responded positively to the use of an online format. No questions were included to specifically evaluate the communication options or social aspect.

In a study conducted by Swan (2001), student satisfaction surveys for an online course were influenced by clarity of course design, interaction with the instructor, and discussions with other students. Aside from the social aspect discussed previously, teacher presence, and course organization were evaluated for this online model. Garrison, et al. (2000) also found teacher presence to be important in online instruction and the development of higher order learning related. This topic received the lowest score from faculty evaluators of this model but was addressed prior to implementation of the model through the addition of videos, instructional text, and encouraging comments. However, it was not reevaluated before or after implementation to ensure that the additions were adequate. In terms of course organization, faculty and student evaluations provided positive results for the organization of content in this course.

The design and structure of this course seemed to correspond with much of the literature regarding online education and constructs related to the Cognitive Flexibility Theory. This suggests that the online format may have utility in yielding positive results for critical thinking improvement when used in conjunction with multimodality, adaptive release, case studies, anchoring, scaffolding, and problem scenarios. Based on student and faculty evaluations, the organization of the course content was presented in beneficial manner. According to Swan (2001), the way that the events of an online course are arranged can influence the success of the course. However, encouraging and monitoring usage of the asynchronous social aspects, along with a reevaluation of the teacher presence may add value to the online learning experience related to this model.

The critical thinking definition adopted by this study and used for model creation was also adopted by the UTMDACC-SHP and stems from the critical thinking skill set utilized by TTU in the development of their Critical Thinking Assessment Test (CAT) (Quality Enhancement Plan, 2010; Tennessee Tech University, 2008). The 12 sub-skills targeted by this model were evaluated by TTU in the validation of their assessment tool. In their evaluation, the score receiving the lowest agreement among faculty was related to the utilization of mathematics in a real-world setting (Stein, et al., 2007). For the evaluation conducted for this model using faculty members from UTMDACC-SHP, this sub-skill received a high score, with the lowest relating to the identification of inappropriate conclusions. When students initially attempted the mathematical sub-skill in the model, they struggled with it, producing one of the three lowest average scores. However, when you considered their attempt with this sub-skill on the summation

module, the average was much higher, indicating that students showed improvement with this sub-skill throughout model usage. The other 11 sub-skills included in this model received high agreement scores when evaluated by TTU in their validation study and high scores by MDACC-SHP faculty when evaluation in conjunction with this model.

The hypothesis of this study was evaluated using the HSRT assessment tool. For the usage of this model, no significant difference was observed for pre-test and post-test scores collected before and after the implementation of the critical thinking model. However, upon further investigation, using regression analysis, it was found that the level of education of a student correlated negatively with the change in HSRT score. No study was found in the literature that specifically compared past educational experience to HSRT score changes. A study conducted by Huhn, Black, Jensen, & Deutsch (2011) found that expert physical therapists scored significantly higher than novice when evaluated at a single time point using the HSRT. Although not a direct correlation with education, it does not contradict the finding in this study. Further investigation of study participants showed that students from junior or community colleges had significantly lower pre-test scores as compared to those from four-year universities or with bachelor's degrees. This study also included past work experience in the analysis and did not find a significant relationship between the past work in a clinical laboratory and HSRT score change.

For this study, the four-year university and bachelor level students showed a 3.5 point higher average on the pre-test than the junior and community college students. A study in the area of nursing evaluated critical thinking skills for first, second, and third year students using the HSRT (Hunter, et al., 2014). Although the study did not aim to

enhance this skill set, it was geared at identifying demographic predictors. In addition to nationality, the study found that year of study correlated with not only the total HSRT score but with all sub-topic scores as well. For each year of study, the critical thinking ability significantly increased for their student population. The third year students showed a 2.4 point average increase over the second year students. Findings of the Hunter, et al., (2014) also noted that these scores did not significantly correlate with age or gender. This study offers support for higher critical thinking skills among more advanced students. It also agrees with this study in finding no relationship between the demographic characteristics of age and gender.

Based on the results of this study, the difference in time spent on the HSRT pre-test and post-test, GPA, and Sakai resource usage were also found to have a significant relationship with the HSRT score change variable. No articles in the literature were found describing a correlation with these variables and the HSRT score change. However, validation studies conducted with similar critical thinking assessment tools found a correlation with GPA. The validation study for the CCTST instrument found a positive relationship between CCTST score and GPA (Facione, Facione, & Giancarlo, 2000). This analysis was based on a single test score and not a pre-test / post-test change value.

For this study, no relationship was found between age and the HSRT change in score. However, like GPA, previous studies with other critical thinking assessment instruments found a correlation with age. A multiple regression study in physical therapy students identified a negative correlation with age (Bartlett & Cox, 2002) and CCTST score change. However, that study only included 28 students and had a mean age of

22. The mean age for study participants included in this study was 27; however, the most common age reported was 22.

Implication of Findings

Although the critical thinking model implemented in this study was not able to significantly enhance the critical thinking skills measured by the HSRT for the population studied, some aspects of the model may prove to be beneficial for a limited group. No direct comparisons could be made to previous studies; however, the literature does support the use of online models presented in an asynchronous format to learners. It also supports the use of case studies for teaching and learning, adaptive release conditions, and multimodality for information delivery.

However, mandating the use of online, asynchronous discussion boards through grading would encourage discussion among students. This would also give the instructor an opportunity to observe the learning process and interject as needed. Although the literature shows that critical thinking can occur without social interactions, the majority of findings support a social aspect. Socratic questioning could be employed in this process. Additionally, the current model does not restrict students from proceeding based on performance. The inclusion of remedial content or personal tutorials by the instructor may be important to enhancing the critical thinking skill set.

The regression model suggests that the critical thinking model developed for this study has the most impact on junior and community college students. Student with more years of education tend to begin with higher critical thinking abilities and show less room for improvement. Therefore, this model may be more beneficial to two plus two clinical laboratory programs, as compared to three plus one formats. Students that enter at a

lower level or institutions that typically recruit junior or community college students may find the most benefit in this model for improving critical thinking skills in their student population.

Additionally, this study indicated that students with higher GPAs showed a greater HSRT score change as compared to those with lower GPAs. This suggests that using GPA scores for admission criteria may help to determine which students have the ability to improve their critical thinking ability and that setting a minimum for admission is beneficial in selecting individuals that can gain the skill set needed for entry level into the profession.

In order to ensure results on the HSRT are truly representative of the student's critical thinking ability and reduce effects of cognitive fatigue or lack of effort, some form of motivation may need to be included. This would encourage students to put forth equal effort as the semester progresses. The observations for this study were only for research purposes and did not contribute to the course grade for students. No incentives or retributions were connected with completion or assessment success. The amount of time spent on the test was significantly less for the second observation as compared to the first and this seemed to predict HSRT score outcome. Additional validity studies are needed; however, content modifications to better target the inference and deduction aspects of critical thinking, discussion board requirements, and a restricted population may prove beneficial in improving critical thinking skills for a subset of clinical laboratory students. This study offers a useful critical thinking definition targeted by a model designed around constructs related to the Cognitive Flexibility

Theory and follows the recommendations and suggestions from previous related publications.

Limitations

There are a number of limitations associated with the one-group, quasi-experimental design used for this study. Potential threats to the internal validity include history, maturation, test effects, instrument effects, and statistical regression towards the mean. Interactions between the selected group and the intervention, as well, as the setting and the intervention are threats to the external validity of this study due to the use of a sample selected from a single institution. Inclusion of a pre-test and post-test can minimize the effects of mortality, compared to a single observation design, but this strategy may increase the test effect. It may also increase the instrument effect, depending on the type of test used. For this study, the instrument effect was well controlled. The common internal and external validity threats were considered in the study design, implementation, and assessment.

Mortality was minimized with the pre-test / post-test assessment format utilized for this study. This strategy allowed for the evaluation of change in critical thinking ability by the same group of students before and after exposure to the critical thinking model. Although the study did have some attrition, this was minimized by the relatively short timeframe. The effects of mortality were reduced because although not all students that took the pre-test assessment also completed the post-test, those without complete scores for both were eliminated from the statistical analysis. Therefore, the pre-test and post-test data used for hypothesis testing was composed of results from the same group of students.

Testing and instrumentation bias were concerns due to the pre-test / post-test format. This study did not strive to determine whether the pre-test provided any learning experience or incentive for students. It has been found that testing effects are more likely to occur when the pre-test data is collected from self-reports (Polit & Beck, 2008), as opposed to the multiple choice format of this testing instrument. For the multiple choice test offered by Insight Assessments (2013), students often remember questions but not responses because they had to reason through the scenario. Instrument bias was well controlled for by the study parameters. The delivery of the pre-test and post-test occurred in a consistent manner, utilizing the same online testing format with constant room conditions and scheduling. To avoid bias reflected through changes in the testing instrument, the same test was used for the pre-test and post-test administration. Grading occurred anonymously through the company providing the test and because of the multiple choice format, was performed in a consistent manner.

It was not possible to eliminate the effects of history and maturation in this study. In order to try and minimize the effect of history, the intervention was implemented into a semester in which no other courses within the programs' curricula were specifically aimed at improving critical thinking skills. However, learning will continue to occur in other courses and through outside experiences. These experiences are not the same for all students and were not controlled or measured in regards to this study. In an effort to limit the influence of maturation, the intervention was centered on topics related to the clinical laboratory discipline, with a hope of maintaining student interest regarding the subject matter. Additionally, the intervention was limited to a single semester and course grades were linked to thoughtful and accurate responses. Nevertheless student

fatigue regarding the subject may still have occurred as the semester progressed. This aspect was not specifically tracked for the study; however, missing assessments and inadequate post-test submissions were monitored.

Regression towards the mean was difficult to evaluate for this study since the test re-test reliability for the HSRT is not published. The group average on the HSRT pre-test was near the national average of 19.8 for other four-year university allied health students (J. Roberts, personal communication, October 22, 2014) and therefore there was less room for the group to regress as a whole. However, individual regression may have been influenced by differences related to prior level of education. Study participants were required to meet the minimum entry level requirements for UTMDACC-SHP. However, no additional scoring criteria or pre-test information was used to select participants; all consenting students were entered into the study, regardless of entry level critical thinking ability.

Another limitation of this study relates to the external validity. This study was only conducted at a single institution, using a convenient sample of students; therefore, the results may not be generalizable to other clinical laboratory technology programs. Two concerns with external validity for this study are interactions between the group selection and intervention and interactions between the setting and intervention. Although the student population at UTMDACC is diverse in age, ethnicity, and gender balanced, this population may not be representative of student body populations seen at other institutions. Additionally, while the UTMDACC educational setting and curriculum meet accreditation requirements, they will vary to some extent in terms of student course load and rigor, compared to other institutions. In an effort to diversify the

population and setting for this study, five clinical laboratory technology programs within laboratory medicine were included. Although these programs are all offered by the same institution, the individual curriculums and student bodies for each program vary. The completed model can be further evaluated by other programs and institutions.

Results based on regression models, rubric scores, and faculty and student evaluations have limited validity. The regression model includes a large number of independent variables and only a limited sample number. Additionally, the results referenced for this model were based on self-reported demographic characteristics and included the addition of average data for missing data points. Rubric scores are based on values produced by an unvalidated instrument. The rubrics had been used previously at UTMDACC-SHP for critical thinking skill evaluation; however, no reliability studies were done. Additionally, all scores were produced by a single scorer. Therefore, no inter-rater reliability could be established. Faculty evaluations were completed by five faculty members, all of which were employed by UTMDACC-SHP. The response rate for student evaluations was only nine percent. Student evaluations should have been required in order to generate a higher response rate. Results generated from these instruments are discussed, along with their implications; however, no conclusions can be drawn without further analysis.

Future Directions

Although this study resulted in no significant change in critical thinking abilities for clinical laboratory technology students after the implementation of the multimodal critical thinking model into the program curriculum, it serves as a starting point for future studies. A number of gaps exist in the literature related to critical thinking and the

clinical laboratory technology profession. Although this study attempted to fill a number of these gaps, more work needs to be done in order to fully evaluate this topic and construct a method for improving the critical thinking skill set in this population. It will also be important to ensure a successful method of implementation, as well as a valid and reliable assessment tool.

Before future use of this model, it needs to be evaluated by a broader group of professionals to confirm the validity of the design. These professionals should represent a variety of clinical laboratory programs from multiple institutions and include several individuals from each of the various disciplines. Upon completion of this evaluation, the model should be tested with a pilot group of students from each of the disciplines. Success and feedback from these students would aid in verifying the validity of the model. Additionally, the rubrics utilized in this study need to be evaluated for reliability and validity.

To minimize additional validity threats, the study could be repeated using a control group. Although it may not be possible to conduct a true experimental analysis with a randomized sample, inclusion of a control group would assist in monitoring the contribution of outside influences, such as skills gained through other course and help better understand the contribution of regression to the mean and cognitive fatigue. By extending this study to multiple institutions, the sample size and statistical power have the potential to increase. Additionally, adding in more institutions will likely result in more generalizable findings. A large, diverse sample would also assist in confirming or contradicting the relationship observed between independent variables, such as test

time, education level, GPA, and Sakai usage and change in HSRT pre-test and post-test scores.

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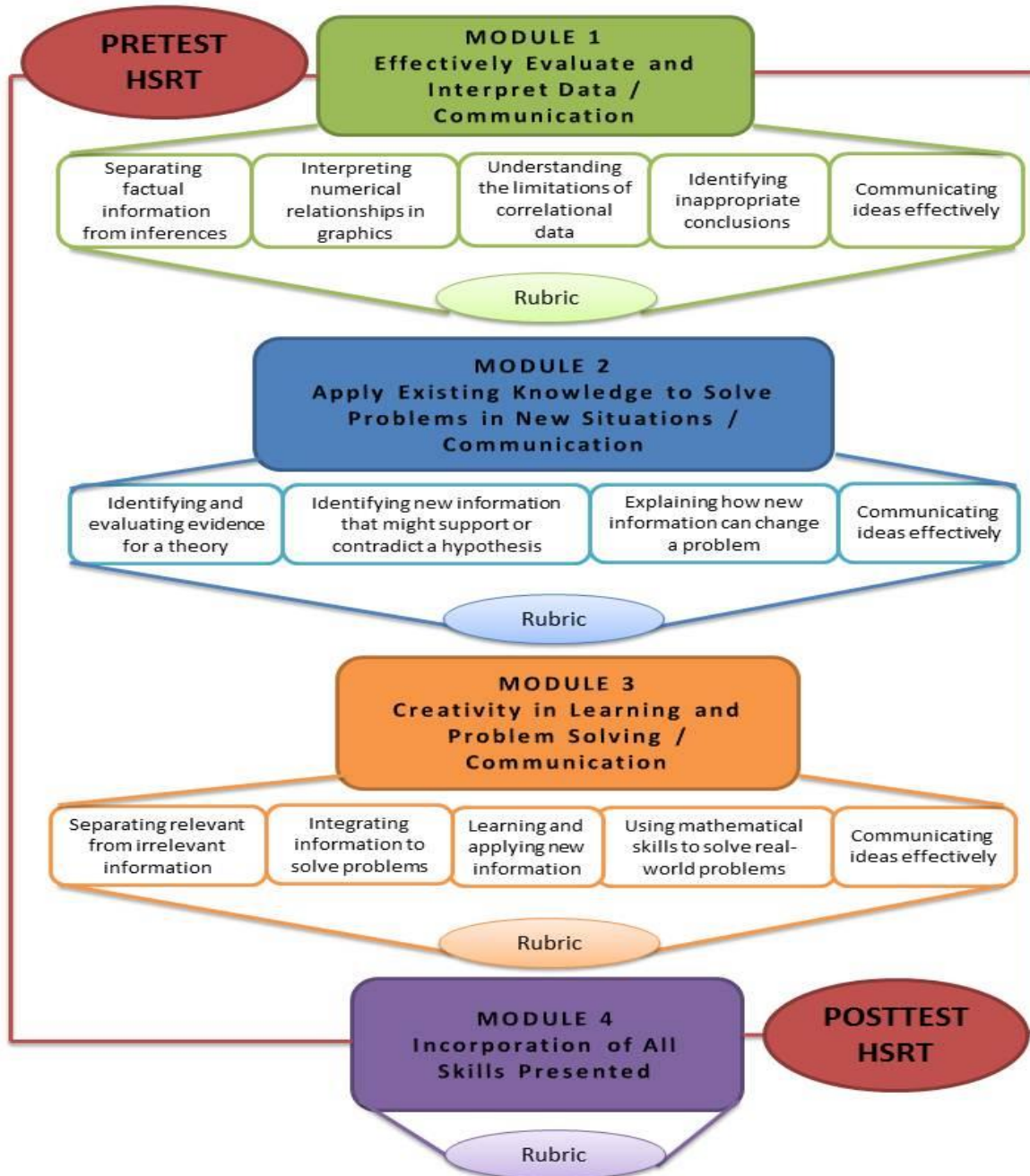
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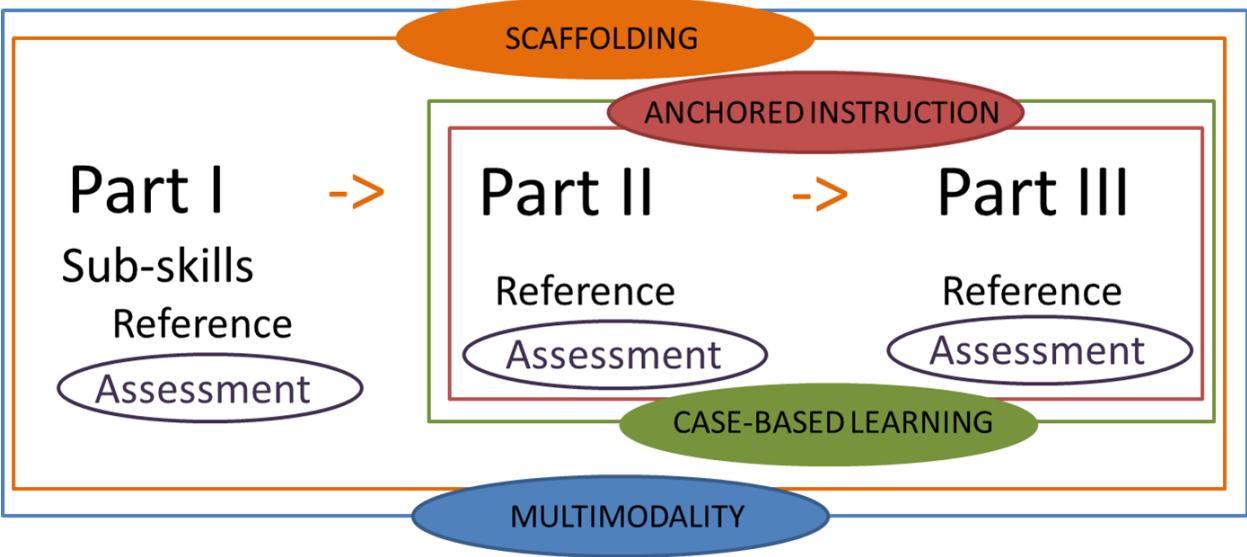
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Appendix - A
Model Overview



Appendix – B
Module Format



Appendix – C
Module Content

Introduction

- References
 - List of critical thinking definitions
 - Video explaining critical thinking
 - Quotes describing the importance of critical thinking skills
 - Video emphasizing importance of critical thinking skills
 - Website evaluation of communication skills
 - Presentation on written communication
 - Link to National Cancer Institute website – lung cancer
- Assessments
 - Questions and Follow-up:
 - Define critical thinking in your own words
 - List three important skills that good critical thinkers have
 - Explain how improving these skills would help you in the future (personally and professionally)
 - Report communication quiz score
 - Evaluate sentence for communication issues
 - Rewrite sentence using proper written communication
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part I materials

Module 1

Effectively Evaluate and Interpret Data

- Part I
 - Subskill 1: Separating factual information from inferences
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short scenario with table: Association between lung cancer patients and follow-up default status
 - Questions: Is each statement a fact or inference
 - Follow-up: Identify assumptions associated with inference statements
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part I - Subskill 2 materials
 - Subskill 2: Interpreting numerical relationships in graphics
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short scenario with graph: U.S. lung cancer mortality by race and gender
 - Questions: What does graph tell us?; What doesn't graph tell us?
 - Follow-up: Evaluate statements for fact or inference; assess underlying assumptions
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part I - Subskill 3 materials
 - Subskill 3: Understanding the limitations of correlational data
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short Scenario with graph: U.S. lung cancer incidence by race and gender
 - Questions: What does graph indicate in regards to lung cancer rates in males over time?; Graph support statement in scenario?; Other explanations?
 - Follow-up: Indicate additional variables potentially contributing to change observed
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part I - Subskill 4 materials
 - Subskill 4: Identify inappropriate conclusions
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short Scenario with statements: Correlation between exercise and lung cancer incidence
 - Questions: Do statements strongly support hypothesis?; Why or why not?
 - Follow-up: State conclusion, identify assumptions associated with conclusion, evaluate validity of assumptions and determine additional information needed to fully evaluate assumptions
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part II materials

Module 1

Effectively Evaluate and Interpret Data

- Part II
 - References
 - Link to lung cancer risk case study article
 - Link to a risk model for prediction of lung cancer publication (Splitz et al, 2007)
 - Link to CDC website – lung cancer risk factors
 - Video link – Fighting lung cancer: lung cancer risk factors (part II)
 - Video reminder from instructor
 - Assessments
 - Short case study: Joe’s risk of developing lung cancer within 5yrs
 - Attached references include: table of risk factors related to case study
 - Questions and Follow-up:
 - Evaluate statements as fact or inference and identify associated assumptions
 - Explain variable relationships in a table and confounding variables
 - Evaluate patient risk overtime and identify other contributing factors
 - Indicate how strongly the data support the hypothesis and explain
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 1: Part III materials

Module 1

Effectively Evaluate and Interpret Data

- Part III
 - References
 - Link to HIV as an independent risk factor for lung cancer (Sigel et al, 2012)
 - Link to smoking, not HIV causes higher lung cancer risk in people with HIV paper (McQueen, 2012)
 - Link to New York department of health website - HIV and cancer: what is the link
 - Link to lung cancer in HIV patients and their parents publication (Engsig et al, 2011)
 - Link to lung cancer Swiss HIV cohort study (Clifford et al, 2012)
 - Link to NCI website – HIV and cancer risk
 - Video reminder from instructor
 - Sub-skill rubrics
 - Assessments
 - Published study: Association between HIV infection and risk for developing lung cancer
 - Attached references include: Publication (Kirk et al, 2007)
 - Questions and Follow-up:
 - Identify statements as fact or inference and associated assumptions
 - Interpret a given figure and justify explanation
 - Explain trends over time and identify other potential explanations
 - Provide support for conclusions given and identify additional information that may be useful in the analysis
 - Communication
 - » Submission to be graded by Module 1: Part III Rubric
 - » Feedback provided
 - » Must submit to gain access to Module 2: Part I – Subskill1 materials

Module 2

Applying Existing Knowledge to Solve Problems in New Situations

- Part I
 - Subskill 1: Identifying and evaluating evidence for a theory
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Theory with concept map: Connection between lung cancer types and subtypes
 - Questions: What evidence from the concept map supports the theory? Justify.
 - Follow-up: Use references to investigate any assumption made; indicate degree of support for the theory
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 2: Part I - Subskill 2 materials
 - Subskill 2: Identifying new information that might support or contradict a hypothesis
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short scenario with problem and reference protocol: Troubleshooting laboratory protocol
 - Questions: What is the hypothesis and what information is needed to evaluate it?
 - Follow-up: Identify type of information needed and explain how it could help solve the problem
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 2: Part I - Subskill 3 materials
 - Subskill 3: Explaining how new information can change a problem
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short Scenario with additional information and assessment guidelines: New test results
 - Questions: Will new information change the diagnosis? If so, how?
 - Follow-up: Identify additional information needed and explain how it will assist in decision making process
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 2: Part II

Module 2

Applying Existing Knowledge to Solve Problems in New Situations

- Part II
 - References
 - Link to NCI website – NSCLC cellular classification
 - Link to images of immunohistochemically stained lung cancer specimens
 - Link to Mayo Clinic – k-ras mutation testing
 - Link to NSCLC diagnosis and predictive analysis publication (Thunnissen et al, 2012)
 - Video reminder from instructor
 - Assessments
 - Short case study: Diagnosing Mr. Jone’s NSCLC
 - Attached references include: NSCLC IHC algorithm, lung cancer diagnosis and prediction flow chart, concept map with lab disciplines
 - Questions and Follow-up:
 - Evaluate a diagram to determine support for a theory and justify explanation
 - Propose a hypothesis for testing potential errors and describe testing method
 - Explain how new test results could change a diagnosis and provide justification
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 2: Part III materials

Module 2

Applying Existing Knowledge to Solve Problems in New Situations

- Part III
 - References
 - Link to diagnosis of lung cancer in small biopsies and cytology publication (Travis et al, 2012)
 - Link to a practical guide for molecular pathology of NSCLC publication (Aisner & Marshall, 2012)
 - Link to detection of ALK fusion in lung cancer with FISH publication (Kobayashi et al, 2012)
 - Link to comparative analysis of immunomarkers in NSCLC biopsies publication (Warth et al, 2012)
 - Video reminder from instructor
 - Sub-skill rubrics
 - Assessments
 - Case study: 31 year old with ALK positive adenocarcinoma of the lung
 - Attached references include: Publication (Shaw et al, 2011)
 - Questions and Follow-up:
 - Use information provided to produce statements in support of a given theory
 - Identify and explain any assumption statements
 - Indicate the level of support provided for a given theory
 - Provide a hypothesis of a evaluating a problem scenario
 - Propose a testing scenario to solve a problem
 - Describe additional information generated through proposed study
 - Evaluate additional information to make diagnostic decisions
 - Determine how new information can alter a problem scenario
 - » Submission to be graded by Module 2: Part III Rubric
 - » Feedback provided
 - » Must submit to gain access to Module 3: Part I – Subskill1 materials

Module 3

Creativity in Learning and Problem Solving

- Part I
 - Subskill 1: Separating relevant from irrelevant information
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short scenario with extra information: Establishing a treatment plan
 - Questions: What type of information would be most helpful in planning?
 - Follow-up: Explain each of your selections
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 3: Part I - Subskill 2 materials
 - Subskill 2: Integrating information to solve problems
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short scenario with flow chart: Defining the treatment plan
 - Questions: What additional information would provide more definitive information?
 - Follow-up: Explain your selection
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 3: Part I - Subskill 3 materials
 - Subskill 3: Learning and applying new information
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short Scenario with new information: Evaluating conflicting advice
 - Questions: How should new information be used to evaluate a situation?
 - Follow-up: Provide statements of support for your answer
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 3: Part I - Subskill 4 materials
 - Subskill 4: Using mathematical skills to solve real-world problems
 - References
 - Terms & Concepts
 - PowerPoint Presentation
 - Assessments
 - Short Scenario with problem: Determining accurate amounts
 - Questions: How much reagent should be used?
 - Follow-up: Justify equation used and explain answer
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 3: Part II materials

Module 3

Creativity in Learning and Problem Solving

- Part II
 - References
 - Video link – lung cancer: molecular tumor testing
 - Link to NCI website – targeted cancer therapies
 - Video link – targeted therapies for lung cancer
 - Link to American Cancer Society website – targeted therapies for NSCLC
 - Link to molecular testing for NSCLC biopsy and cytology specimen publication (Wistuba, 2012)
 - Video reminder from instructor
 - Assessments
 - Short case study: Determining the best treatment option of Mr. Z
 - Attached references include: NSCLC algorithm for molecular testing, mutational overlap in NSCLC, clinical trial information for MET kinase inhibitor, and mutations by smoking history
 - Questions and Follow-up:
 - Determine the most informative test using the information provided
 - Provide supportive statements for the chosen test
 - Integrate reference information into the provided information to answer diagnostic questions
 - Use new information to determine test outcomes
 - Explain how new information can be used in the decision making process
 - Evaluate mathematical information presented
 - Indicate how to solve a mathematical problem
 - » Submission for participation
 - » Immediate feedback provided
 - » Must submit to gain access to Module 2: Part II materials

Module 3

Creativity in Learning and Problem Solving

- Part III
 - References
 - Link to molecular pathology of lung cancer: key to personalized medicine publication (Cheng et al, 2012)
 - Link to multiplexed genotyping of NSCLC in clinical practice publication (Sequist et al, 2011)
 - Link to Online Mendelian Inheritance in Man database – EGFR
 - Link to OMIM database – ALK/EML4
 - Link to OMIM database – K-RAS
 - Link to OMIM database – MET
 - Link to NCI website – Gefinitib
 - Video reminder from instructor
 - Sub-skill rubrics
 - Assessments
 - Case study: 26-year old man with back pain and mass in the lung
 - Attached references include: published case study (Sequist et al, 2008), diagnostic strategies for unknown primary tumor identification, algorithms for mutational analysis of lung adenocarcinomas, mutations by smoking history, mutational overlap in NSCLC, EGFR variants, and mutations related to tyrosine kinase inhibitor non-response
 - Questions and Follow-up:
 - Determine useful information for confirming diagnostic findings
 - Evaluate algorithms for determining optimal treatment strategies
 - Evaluate how new information will effect a treatment decision
 - Calculate the amount of sample needed to perform an assay
 - Indicate additional information most useful in solving a given problem
 - Analyze facts presented to determine the next course of action
 - Use new information to evaluate a given course of treatment
 - Evaluate drug calculations to determine whether the correct dose is being administered
 - Communication
 - » Submission to be graded by Module 3: Part III Rubric
 - » Feedback provided
 - » Must submit to gain access to Module 4 materials

Module 4

Incorporation of All Skills Presented

- **References**
 - Note stating that no additional reference information is provided for this module
 - Video reminder from instructor
- **Assessments**
 - Case study: Primary lung cancer in an 18-year old boy
 - Attached references included: Case study publication (Fukuda et al, 1990), cancer deaths in Japan, IHC staining results by site, diagnostic strategies for identifying unknown primary cancers, proposed test algorithm, mutational overlap in NSCLC, mutations by smoking history, surfactant apoprotein A results, lung cancer concept map, testing reference ranges, lung cancer signs and symptoms, serum cancer antigen 125 levels, and causes of lung cancer in non-smokers
 - Questions and Follow-up:
 - Differentiate between factual statements and inferences
 - Use graphical representations of data to evaluate given statements
 - Determine level of support for or against a given statement using graphical information
 - Identify correlational data and appropriate conclusions that can be drawn
 - Evaluate the validity of a given statement using information provided
 - Use multiple reference sources to determine the level of support for a given conclusion
 - Identify the parts of a hypothesis statement
 - Propose a study to investigate the proposed hypothesis statement
 - Evaluate additional information presented and determine how it might change the diagnostic situation
 - Determine what additional testing information would provide the most useful information for assessing the scenario
 - Apply new information to a given algorithm to determine what additional information may assist in problem solving
 - Evaluate whether or not new information will change the prescribed treatment regiment
 - Determine relevant information supplied in a given scenario regarding patient outcome
 - Calculate the appropriate drug dosage for administration
 - Communication
 - » Submission to be graded by Modules 1-3: Part III Rubrics
 - » Feedback provided
 - » Must submit to complete final module

Appendix – D
Faculty Evaluation

Faculty Review Committee –

Thank you for agreeing to evaluate the critical thinking model developed as part of my dissertation entitled Enhancing Critical Thinking in Clinical Laboratory Technology Students: A Multimodal Model. The aims of this project are to develop, implement, and assess a critical thinking model and its ability to improve critical thinking skills in this study population. The designed model will be implemented into HS3270: Critical Thinking for Health Professions and assessed in a pre-test / post-test format using the Health Science Reasoning Test. The model has been aligned with the following critical thinking definition adopted by the University of Texas M.D. Anderson’s School of Health Professions: Critical thinking includes the ability to effectively evaluate and interpret data; apply existing knowledge to solve problems; demonstrate creativity and resourcefulness; and effectively and persuasively communicate findings.

The model (see last page) is composed of an introduction followed by four modules. The first three modules are divided into three parts. The first part of each module includes a section devoted to each targeted critical thinking sub-skill. The second and third parts each module are designed to target all sub-skills targeted by the module. Reference material and assessments, with immediate feedback, are found in parts one and two. The third parts contain only assessments, which will be graded with a rubric. The fourth module is designed to incorporate all sub-skills targeted by the complete model. See last page for the complete model design.

Please complete the evaluation by reviewing the critical thinking model in Sakai and ranking each part of the assessment below using the following scale:

1 = very poor

2 = poor

3 = fair

4 = good

5 = very good

To what degree does the reference material and assessment found in Part I of Modules 1 – 3 address each sub-skill?

Module 1: Part I – Sub-skill 1: Separating factual information from inferences

1 2 3 4 5 Comments: _____

Module 1: Part I – Sub-skill 2: Interpreting numerical relationships in graphics

1 2 3 4 5 Comments: _____

Module 1: Part I – Sub-skill 3: Understanding the limitations of correlational data

1 2 3 4 5 Comments: _____

Module 1: Part I – Sub-skill 4: Identifying inappropriate conclusions

1 2 3 4 5 Comments: _____

Module 2: Part I – Sub-skill 1: Identifying and evaluating evidence for a theory

1 2 3 4 5 Comments: _____

Module 2: Part I – Sub-skill 2: Identifying new information that might support / contradict a hypothesis

1 2 3 4 5 Comments: _____

Module 2: Part I – Sub-skill 3: Explaining how new information can change a problem

1 2 3 4 5 Comments: _____

Module 3: Part I – Sub-skill 1: Separating relevant from irrelevant information

1 2 3 4 5 Comments: _____

Module 3: Part I – Sub-skill 2: Integrating information to solve problems

1 2 3 4 5 Comments: _____

Module 3: Part I – Sub-skill 3: Learning and applying new information

1 2 3 4 5 Comments: _____

Module 3: Part I – Sub-skill 4: Using mathematical skills to solve real-world problems

1 2 3 4 5 Comments: _____

To what degree does the reference material and assessment found in Part II of each module address all associated sub-skills?

Module 1: Part II

Sub-skill 1: Separating factual information from inferences

1 2 3 4 5

Sub-skill 2: Interpreting numerical relationships in graphics

1 2 3 4 5

Sub-skill 3: Understanding the limitations of correlational data

1 2 3 4 5

Sub-skill 4: Identifying inappropriate conclusions

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

Module 2: Part II

Sub-skill 1: Identifying and evaluating evidence for a theory

1 2 3 4 5

Sub-skill 2: Identifying new information that might support / contradict a hypothesis

1 2 3 4 5

Sub-skill 3: Explaining how new information can change a problem

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

Module 3: Part II

Sub-skill 1: Separating relevant from irrelevant information

1 2 3 4 5

Sub-skill 2: Integrating information to solve problems

1 2 3 4 5

Sub-skill 3: Learning and applying new information

1 2 3 4 5

Sub-skill 4: Using mathematical skills to solve real-world problems

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

To what degree does the assessment found in Part III of Modules 1 – 3 and Module 4 address all associated sub-skills?

Module 1: Part III

Sub-skill 1: Separating factual information from inferences

1 2 3 4 5

Sub-skill 2: Interpreting numerical relationships in graphics

1 2 3 4 5

Sub-skill 3: Understanding the limitations of correlational data

1 2 3 4 5

Sub-skill 4: Identifying inappropriate conclusions

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

Module 2: Part III

Sub-skill 1: Identifying and evaluating evidence for a theory

1 2 3 4 5

Sub-skill 2: Identifying new information that might support / contradict a hypothesis

1 2 3 4 5

Sub-skill 3: Explaining how new information can change a problem

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

Module 3: Part III

Sub-skill 1: Separating relevant from irrelevant information

1 2 3 4 5

Sub-skill 2: Integrating information to solve problems

1 2 3 4 5

Sub-skill 3: Learning and applying new information

1 2 3 4 5

Sub-skill 4: Using mathematical skills to solve real-world problems

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

Module 4

Separating factual information from inferences

1 2 3 4 5

Interpreting numerical relationships in graphics

1 2 3 4 5

Understanding the limitations of correlational data

1 2 3 4 5

Identifying inappropriate conclusions

1 2 3 4 5

Identifying and evaluating evidence for a theory

1 2 3 4 5

Identifying new information that might support / contradict a hypothesis

1 2 3 4 5

Explaining how new information can change a problem

1 2 3 4 5

Separating relevant from irrelevant information

1 2 3 4 5

Integrating information to solve problems

1 2 3 4 5

Learning and applying new information

1 2 3 4 5

Using mathematical skills to solve real-world problems

1 2 3 4 5

Communicating ideas effectively

1 2 3 4 5

Comments: _____

To what degree does each module and associated parts address critical thinking?

Module 1: Part I

1 2 3 4 5 Comments: _____

Module 1: Part II

1 2 3 4 5 Comments: _____

Module 1: Part III

1 2 3 4 5 Comments: _____

Module 2: Part I

1 2 3 4 5 Comments: _____

Module 2: Part II

1 2 3 4 5 Comments: _____

Module 2: Part III

1 2 3 4 5 Comments: _____

Module 1: Part I

1 2 3 4 5 Comments: _____

Module 3: Part II

1 2 3 4 5 Comments: _____

Module 3: Part III

1 2 3 4 5 Comments: _____

Module 4

1 2 3 4 5 Comments: _____

Overall Model

1 2 3 4 5 Comments: _____

Please rank the following:

Overall model design

1 2 3 4 5

Comments: _____

Topic chosen (lung cancer)

1 2 3 4 5

Comments: _____

Amount of reference information provided

1 2 3 4 5

Comments: _____

Level of reference information provided

1 2 3 4 5

Comments: _____

Level of assessment

1 2 3 4 5

Comments: _____

Ease of use / navigation

1 2 3 4 5

Comments: _____

Platform chose (Sakai)

1 2 3 4 5

Comments: _____

Delivery method (online)

1 2 3 4 5

Comments: _____

Instructor presence

1 2 3 4 5

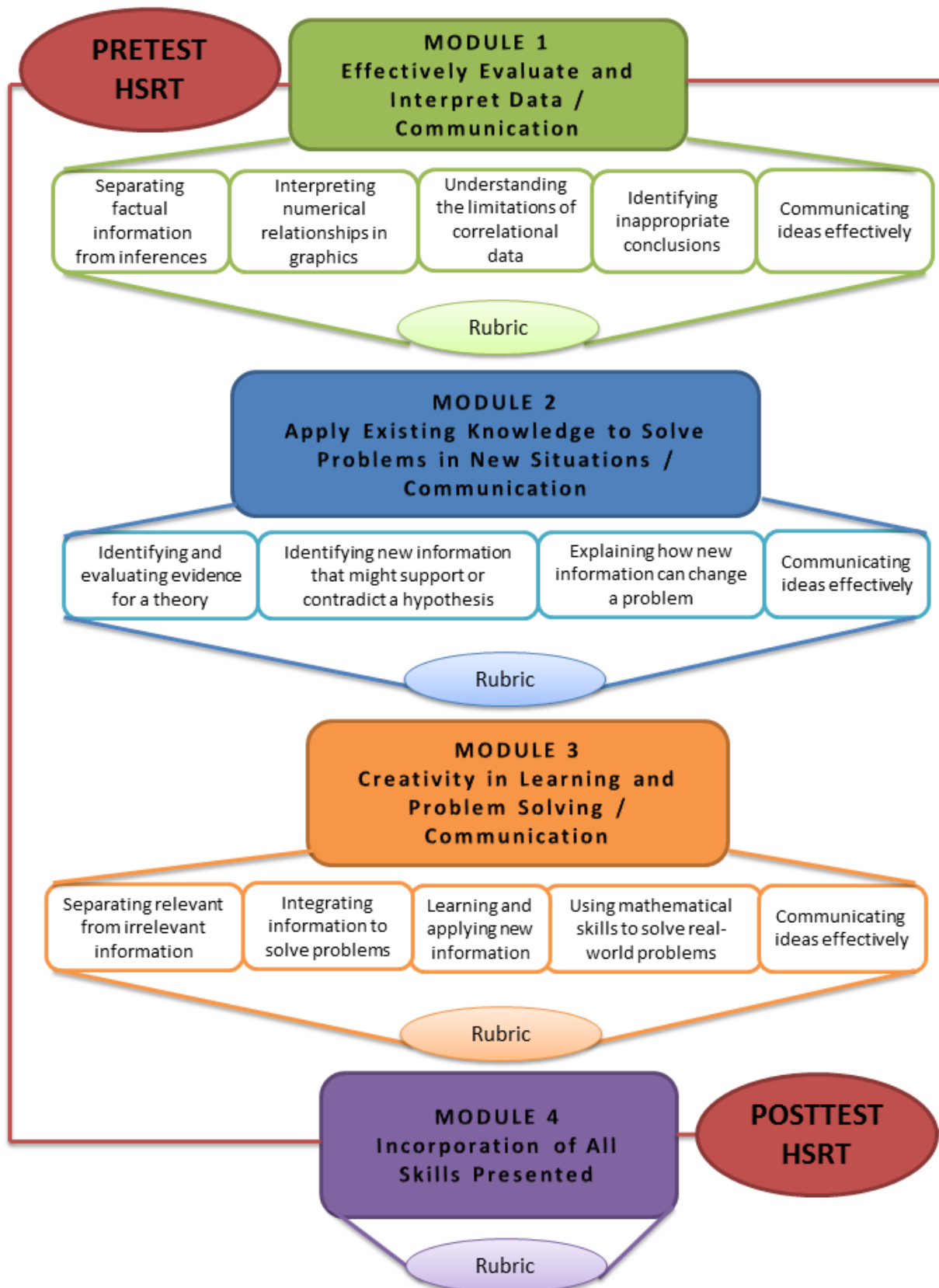
Comments: _____

Usefulness of feedback provided

1 2 3 4 5

Comments: _____

Additional comments:



Appendix – E
Student Evaluation

1. Select the option that best reflects your view of the organization of the course, in terms of modules and parts. Feel free to add comments related to this topic below.

Excellent

Okay

Questionable

Poor

2. Select the option that best reflects your view of the delivery style of the course, in terms the online format. Feel free to add comments related to this topic below.

Excellent

Okay

Questionable

Poor

3. Select the option that best reflects your view of the course content, in terms of concepts addressed. Feel free to add comments related to this topic below.

Excellent

Okay

Questionable

Poor

4. Select the option that best reflects your feelings concerning the course topic of lung cancer and laboratory testing.

Excellent

Okay

Questionable

Poor

5. To what degree do you feel that each of the following objectives or sub-skills was met:

Poor Questionable Okay Excellent

Module 1 - Sub-skill 1:
Separating
factual
information
from inferences

Module 1 - Sub-skill 2:
Interpreting
numerical
relationships in
graphics

Module 1 - Sub-skill 3:
Understanding
the limitations
of correlational
data

5. To what degree do you feel that each of the following objectives or sub-skills was met:

Module 1 - Sub-skill 4:
Identifying inappropriate conclusions

Module 2 - Sub-skill 1:
Identifying and evaluating evidence for a theory

Module 2 - Sub-skill 2:
Identifying new information that might support / contradict a hypothesis

Module 2 - Sub-skill 3:
Explaining how new information can change a problem

Module 3 - Sub-skill 1:
Separating relevant from irrelevant information

Module 3 - Sub-skill 2:
Integrating information to solve problems

5. To what degree do you feel that each of the following objectives or sub-skills was met:

Module 3 - Sub-skill 3: Learning and applying new information

Module 3 - Sub-skill 4: Using mathematical skills to solve real-world problems

Included in all modules:
Communicating ideas effectively

6. Rate the usefulness of the reference material for each module and part:

	Not really useful	Somewhat useful	Very useful
--	-------------------	-----------------	-------------

Introduction

Module 1 - Part I

Module 1 - Part II

Module 1 - Part III

Module 2 - Part I

Module 2 - Part II

6. Rate the usefulness of the reference material for each module and part:

Module 2 - Part III

Module 3 - Part I

Module 3 - Part II

Module 3 - Part III

7. What did you like most about this course?

8. What did you like least about this course?

9. What changes could be made to improve this course?

10. Overall, did you find this course beneficial?

Yes

Somewhat

No

Appendix – F
Demographic Questionnaire

Demographic Questionnaire

The following demographic information will be collected as part of the pre-test and post-test assessment provided by Insight Assessment. Other than age, student id number, and GPA, all options will appear in a drop down menu that allows the students to select one option. For age, student id number, and GPA, free text will be entered by the student.

Which program are you enrolled in?

CLS

CGT

MGT

CT

HT

Is English your primary language?

Yes

No

What is your comfort level with English?

Excellent

Good

Moderate

Low

Poor

Student id number _____

GPA _____

What is your past educational experience? (select all that apply)

Attended a junior or community college

Attended a 4-year university or college

Completed a bachelor's degree

Completed a master's degree

Completed a PhD or other doctoral level degree

How much work experience do you have?

I have never worked in a laboratory environment

I have worked in a laboratory environment for less than 2 years

I have worked in a laboratory environment for 2-5 years

I have worked in a laboratory environment for greater than 5 years

Ethnicity

Black, African American

White, Caucasian, Anglo American

Asian, Asian American, Pacific Islander

Hispanic, Latino, Mexican American

American Indian / Native American

Other

I choose not to provide this information

Gender

Male

Female

I choose not to provide this information

Age

Appendix – G
Model Delivery Schedule

Model Delivery Schedule

	ASSESSMENT			DUE DATE
<i>Observation 1</i>	HSRT Pre-test			September 9, 2013
<i>Intervention</i>	Introduction to Critical Thinking / Communication			September 16, 2013
	Module 1 : Effectively Evaluate and Interpret Data	Part I	Sub-skill 1: Separating factual information from inferences	September 23, 2013
			Sub-skill 2: Interpreting numerical relationships in graphics	September 23, 2013
			Sub-skill 3: Understanding the limitations of correlational data	September 23, 2013
			Sub-skill 4: Identify inappropriate conclusions	September 23, 2013
		Part II		September 30, 2013
		Part III		October 7, 2013
		Module 2 : Apply Existing Knowledge to Solve Problems in New Situations	Part I	Sub-skill 1: Identifying and evaluating evidence for a theory
	Sub-skill 2: Identifying new information that might support or contradict a hypothesis			October 14, 2013
	Sub-skill 3: Explaining how new information can change a problem			October 14, 2013
	Part II			October 21, 2013
	Part III			October 28, 2013
	Module 3: Creativity in Learning and Problem Solving	Part I	Sub-skill 1: Separating relevant from irrelevant information	November 4, 2013
			Sub-skill 2: Integrating information to solve problems	November 4, 2013
			Sub-skill 3: Learning and applying new information	November 4, 2013
			Sub-skill 4: Using mathematical skills to solve real-world problems	November 4, 2013
		Part II		November 11, 2014
		Part III		November 18, 2014
	Module 4: All Skills Presented			December 2, 2013
	<i>Observation 2</i>	HSRT Post-test		

Appendix – H
Assessment Rubrics

Module 1: PART III RUBRIC

Effectively Evaluate and Interpret Data

- **Subskill 1: Separating factual information from inferences**
 - 5pts – Not only identifies and avoids all mistakes of reasoning but give clear explanations of why they are mistakes
 - 4pts – Identifies and avoids all mistakes of reasoning and explains some of them
 - 3pts – Successfully identifies and avoids some common mistakes of reasoning but misses less common ones, and does not explain why or how they are mistakes
 - 2pts – Fails to identify and explain mistakes in reasoning of others and fails to avoid them in his or her own reasoning
 - 1pt – makes no response
- **Subskill 2: Interpreting numerical relationships in graphics**
 - 5pts – Consistently does all or almost all of the following: accurately interprets evidence, statements, graphics, questions, etc; identifies the salient arguments pro and cons; thoughtfully analyzes and evaluates major alternative points of view; draws warranted, judicious, non-fallacious conclusions; justifies key results and procedures, explains assumptions and reasons
 - 4pts – Does most or many of the following: accurately interprets evidence, statements, graphics, questions, etc; identifies the salient arguments pro and cons; thoughtfully analyzes and evaluates major alternative points of view; draws warranted, judicious, non-fallacious conclusions; justifies key results and procedures, explains assumptions and reasons
 - 3pts – Does most or many of the following: misinterprets evidence statements, graphics, questions, etc; fails to identify strong, relevant counter-arguments; ignores or superficially evaluates obvious alternative points of view; draws unwarranted or fallacious conclusions; justifies few results or procedures, seldom explains reasons
 - 2pts – Consistently does all or most all of the following: offers biased interpretations of evidence, statements, graphics, questions, information, or the points of view of others; fails to identify or hastily dismisses strong, relevant counter-arguments; ignores or superficially evaluates obvious alternative points of view; argues using fallacious or irrelevant reasons, and unwarranted claims; does not justify results or procedures, nor explain reasons
 - 1pt – Makes no interpretation of graphics
- **Subskill 3: Understanding limitations to correlational data**
 - 5pts – Uses scientific concepts, models, terminology and/or notation with minimal errors to report results, discuss relationships, and propose explanations; explicitly analyzes the results of the investigation to support conclusions which address the question/hypothesis and any relationships discovered; provides evidence that the design, procedures, and results have been reviewed to identify important limitations and sources of error
 - 4pts – Uses scientific concepts, models, and/or terminology with minimal errors to report results, identify patterns, and propose explanations; explicitly uses the results of the investigation to support conclusions which address the questions/hypothesis; provides evidence that the design, procedures, and result have been reviewed to identify some obvious limitations or sources of error
 - 3pts – Uses scientific concepts, models, or terminology to report results and, with some significant errors, identify patterns and propose explanations; develops conclusions related to the question/hypothesis but support from the investigation is either incomplete or not explicit; summarizes the design, procedures, and results but deals with error and limitations in trivial or illogical manner
 - 2pts – Uses scientific concepts, models, or terminology incorrectly to report results, identify patterns and/or propose explanations; presents interpretations or conclusions which are not clearly related to the question/hypothesis or supported by the results; summarizes the investigation in a general or somewhat unclear way
 - 1pt – Does not clearly explain results or use scientific knowledge correctly; does not present clear, logical, or supported interpretations; does not clearly review or summarize the investigation
- **Subskill 4: Identifying inappropriate conclusions**
 - 5pts – Clearly states conclusions, shows how it emerges from the evidence, demonstrates its relationship to given question
 - 4pts – States conclusion, shows how it emerges from the evidence, answers the given question
 - 3pts – Indicates conclusion, answers the question but explanation is weak and not supported by evidence
 - 2pts – Wanders from the given question
 - 1pt – Proposes no comprehensible conclusion
- **Communicating ideas effectively**
 - 5pts – Demonstrates a fuller knowledge of information than required; topic covered thoroughly; abundance of material clearly related to thesis; controlled flow and interesting sequence of material; presentation length entirely appropriate for topic and assignment; balanced use of multimedia materials properly used to develop thesis
 - 4pts – Demonstrates expected knowledge of information; enough information given to understand topic; points clearly made and all evidence supports thesis; presentation length acceptable; good variety and blending of materials/media
 - 3pts – Student demonstrates basic knowledge of information; thesis apparent; information relates to thesis; rarely excludes important information or includes unnecessary information; logical sequence of information; presentation length of minor concern; use of multimedia not as varied but connected to thesis
 - 2pts – Does not have full grasp of information; information does not always support thesis; excludes some important information and includes some unnecessary information; flow and organization is choppy; concepts and ideas loosely connected; presentation length not adequate to cover assigned material; multimedia not clearly connected to thesis
 - 1pt – Shows no understanding of material; topic not covered adequately; no conclusion to summarized presentation; no logical sequence of information; inappropriate type of presentation for topic/audience; presentation distracting; incoherent; presentation length far from assigned requirement; multimedia does not support presentation

Module 2: PART III RUBRIC

Applying Existing Knowledge to Solve Problems in New Situations

- **Subskill 1: Identifying and evaluating evidence for a theory**
 - 5pts – The work demonstrates surprising/insightful ability to take ideas/theories/processes/principles further into new territory, broader generalizations, hidden meanings and implications as well-as well as to assess discriminately the value, credibility and power of these ideas in order to decide on well-considered choices and opinions
 - 4pts – The work demonstrates adequate ability to take ideas/theories/processes/principles further into new territory, broader generalizations, hidden meanings and implications as well-as well as a to assess discriminately the value, credibility and power of these ideas in order to decide on well-considered choices and opinions
 - 3pts – The work demonstrates uneven and superficial ability to take ideas/theories/processes/principles further into new territory, broader generalizations, hidden meanings and implications as well-as well as a limited ability to assess discriminately the value, credibility and power of these ideas in order to decide on well-considered choices and opinions
 - 2pts – The work demonstrates little ability to take ideas/theories/processes/principles further into new territory, broader generalizations, hidden meanings and implications as well-as well as a limited and superficial ability to assess discriminately the value, credibility and power of these ideas in order to decide on well-considered choices and opinions
 - 1pt – The work demonstrates no ability to take ideas/theories/processes/principles further into new territory, broader generalizations, hidden meanings and implications as well-as well as a limited and superficial ability to assess discriminately the value, credibility and power of these ideas in order to decide on well-considered choices and opinions
- **Subskill 2: Identifying new information that might support or contradict a hypothesis**
 - 5pts – Clearly states conclusion or hypothesis, shows how it emerges from the evidence of new information, demonstrates its relationship to given question
 - 4pts – States conclusion or hypothesis, shows how it emerges from the evidence of new information, answers the given question
 - 3pts – Indicates conclusion or hypothesis, answers the question but explanation is weak and not supported by evidence of new information
 - 2pts – Wanders from the given question
 - 1pt – Proposes no comprehensible conclusion or hypothesis, or does not discuss new information
- **Subskill 3: Explaining how new information can change a problem**
 - 5pts – Clearly states the problem, convincingly defining the scope and establishing why it needs to be solved; clearly states the solution, and convincingly proves that it is effective, feasible, acceptable to those involved, and better than alternatives; anticipates and considers opposing views or objections and effectively addresses, accommodates or refutes them
 - 4pts – States the problem, indicates a mention of the scope and need; states the solution and proves it is effective, feasible, acceptable to those involved, and better than alternatives; anticipates some opposing views or objections and begins to address them
 - 3pts – States the problem, but incompletely; states the solution, but incompletely; opposing views and objections are incompletely considered and addressed
 - 2pts – Statement of problem is unclear and poorly defined; no need is established; statement of solution is unclear; solution seems ineffective, unfeasible, unacceptable to those involved or not preferable to alternatives; opposing views and objections are not considered
 - 1pt – Proposes no statement of problem and offers no explanation of how new information impacts the problem
- **Communicating ideas effectively**
 - 5pts – Demonstrates a fuller knowledge of information than required; topic covered thoroughly; abundance of material clearly related to thesis; controlled flow and interesting sequence of material; presentation length entirely appropriate for topic and assignment; balanced use of multimedia materials properly used to develop thesis
 - 4pts – Demonstrates expected knowledge of information; enough information given to understand topic; points clearly made and all evidence supports thesis; presentation length acceptable; good variety and blending of materials/media
 - 3pts – Student demonstrates basic knowledge of information; thesis apparent; information relates to thesis; rarely excludes important information or includes unnecessary information; logical sequence of information; presentation length of minor concern; use of multimedia not as varied but connected to thesis
 - 2pts – Does not have full grasp of information; information does not always support thesis; excludes some important information and includes some unnecessary information; flow and organization is choppy; concepts and ideas loosely connected; presentation length not adequate to cover assigned material; multimedia not clearly connected to thesis
 - 1pt – Shows no understanding of material; topic not covered adequately; no conclusion to summarized presentation; no logical sequence of information; inappropriate type of presentation for topic/audience; presentation distracting; incoherent; presentation length far from assigned requirement; multimedia does not support presentation

Module 3: PART III RUBRIC

Effectively Evaluate and Interpret Data

- **Subskill 1: Separating relevant from irrelevant information**
 - 5pts – Consistently distinguishes between relevant and irrelevant information
 - 4pts – Distinguishes between relevant and irrelevant information most of the time
 - 3pts – Inconsistently distinguishes between relevant and irrelevant information
 - 2pts – Consistently fails to distinguish between relevant and irrelevant information
 - 1pt – Makes no attempt to discuss information
- **Subskill 2: Integrating information to solve problems**
 - 5pts – Clearly states the problem, convincingly defining the scope and establishing why it needs to be solved; clearly states the solution, and convincingly proves that it is effective, feasible, acceptable to those involved, and better than alternatives; anticipates and considers opposing views or objections and effectively addresses, accommodates or refutes them
 - 4pts – States the problem, including a mention of the scope and need; states the solution and proves it is effective, feasible, acceptable to those involved, and better than alternatives; anticipates some opposing views or objections and begins to address them
 - 3pts – States the problem, but incompletely; states the solution, but incompletely; opposing views and objections are incompletely considered and addressed
 - 2pts – Statement of problem is unclear and poorly defined; no need is established; statement of solution is unclear; solutions unclear; solution seems ineffective, unfeasible, unacceptable to those involved or not preferable to alternatives; opposing views and objectives are not considered
 - 1pt – No attempt to state the problem; no attempt to state a solution or to consider information for a solution
- **Subskill 3: Learning and applying new information**
 - 5pts – The work demonstrates confident ability to work with the key concepts/information/process/theory-applying or extending them to a wide variety of new problems or contexts, making predictions, recognizing hidden meanings, drawing inferences, analyzing patterns and component parts, communicating insightful contrasts and comparisons
 - 4pts – The work demonstrates adequate ability to work with the key concepts/information/process/theory-applying or extending them to a wide variety of new problems or contexts, making predictions, recognizing hidden meanings, drawing inferences, analyzing patterns and component parts, communicating insightful contrasts and comparisons
 - 3pts – The work demonstrates uneven and shaky ability to work with the key concepts/information/process/theory-applying or extending them to a wide variety of new problems or contexts, making predictions, recognizing hidden meanings, drawing inferences, analyzing patterns and component parts, communicating insightful contrasts and comparisons
 - 2pts – The work demonstrates extremely limited ability to work with the key concepts/information/process/theory-applying or extending them to a wide variety of new problems or contexts, making predictions, recognizing hidden meanings, drawing inferences, analyzing patterns and component parts, communicating insightful contrasts and comparisons
 - 1pt – The work demonstrates no ability to work with the key concepts/information/process/theory-applying or extending them to a wide variety of new problems or contexts, making predictions, recognizing hidden meanings, drawing inferences, analyzing patterns and component parts, communicating insightful contrasts and comparisons
- **Subskill 4: Using mathematical skills to solve real-world problems**
 - 5pts – Solution shows complete understanding of the mathematical concepts used to solve the problem(s)
 - 4pts – Solution shows substantial understanding of the mathematical concepts used to solve the problem(s)
 - 3pts – Solution shows some understanding of the mathematical concepts needed to solve the problem(s)
 - 2pts – Solution shows very limited understanding of the underlying concepts needed to solve the problem(s)
 - 1pt – Solution shows no understanding of the underlying concepts needed to solve the problem(s) OR is not written
- **Communicating ideas effectively**
 - 5pts – Demonstrates a fuller knowledge of information than required; topic covered thoroughly; abundance of material clearly related to thesis; controlled flow and interesting sequence of material; presentation length entirely appropriate for topic and assignment; balanced use of multimedia materials properly used to develop thesis
 - 4pts – Demonstrates expected knowledge of information; enough information given to understand topic; points clearly made and all evidence supports thesis; presentation length acceptable; good variety and blending of materials/media
 - 3pts – Student demonstrates basic knowledge of information; thesis apparent; information relates to thesis; rarely excludes important information or includes unnecessary information; logical sequence of information; presentation length of minor concern; use of multimedia not as varied but connected to thesis
 - 2pts – Does not have full grasp of information; information does not always support thesis; excludes some important information and includes some unnecessary information; flow and organization is choppy; concepts and ideas loosely connected; presentation length not adequate to cover assigned material; multimedia not clearly connected to thesis
 - 1pt – Shows no understanding of material; topic not covered adequately; no conclusion to summarized presentation; no logical sequence of information; inappropriate type of presentation for topic/audience; presentation distracting; incoherent; presentation length far from assigned requirement; multimedia does not support presentation

Vita

Denise Marie Juroske Short was born on December 29, 1977, in Victoria, Texas. She graduated from Industrial High School, Vanderbilt, Texas in 1996. She received her Bachelor of Science with a double major in Biochemistry and Genetics from Texas A&M University, College Station, Texas in 2001 and subsequently worked as a as a Research Assistant in the Thoracic Head and Neck Medical Oncology Department at the University of Texas M.D. Anderson Cancer Center (UTMDACC) for four years. She received a second Bachelor of Science in Molecular Genetic Technology from UTMDACC's School of Health Professions, Houston, Texas in 2005 and her Master of Science in Forensic Science from Oklahoma State University, Tulsa, Oklahoma in 2006. Her specialty track was DNA analysis, and she worked as a Graduate Assistant in the Human Identity Laboratory before being employed by the Harris County Medical Examiner's Office, Houston, Texas as a DNA Analyst. After a year she transitioned to a Senior Health Professions Educator at UTMDACC's School of Health Professions where she taught with the Molecular Genetics Technology Program. She was later promoted to Instructor and served this program for a total of seven years. In 2014 she relocated to Knoxville, Tennessee and continued to teach part-time with UTMDACC's School of Health Professions in an Adjunct Faculty position. She received her Doctorate of Philosophy in Health Related Sciences from Virginia Commonwealth University, Richmond, Virginia in 2014. Her specialty track was in Clinical Laboratory Science. She

was certified in Molecular Biology through the American Society of Clinical Pathology and has remained certified for the past eight years. She serves as Secretary and Treasurer for the Association of Genetic Technologists and is a member of the Association for Molecular Pathology, American Society for Clinical Laboratory Science, and Texas Society of Allied Health Professions.