CALCULUS CONCEPT INVENTORY: CREATION AND USE IN FIRST SEMESTER CALCULUS IN A COMMUNITY COLLEGE SETTING

by

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ABSTRACT

The purpose of this research was to (1) develop a calculus concept inventory (CCI), and (2) compare how students in traditional calculus classes performed as compared to those in a fully integrated calculus-physics learning community on the CCI. The CCI was developed to address misinformed foundational beliefs students may have about mathematical concepts within calculus. Research areas examined included the following: (1) development of a CCI which included conceptual misconceptions, (2) utilization of CCI to review commonsense misconceptions, and (3) determine whether the calculus/physics learning community addressed common misconceptions better than traditional calculus courses.

This quantitative study was a quasi-experimental and nonequivalent group design. As a result of student interviews and reviewing student work, a CCI was developed. The results between the learning community and traditional students were statistically significant on the pre, post, and difference scores, but were not statistically significant on the Hake gain. After further review of the data, most of the faculty in the learning community had been teaching less than 2 years in the learning community, and this may have impacted the results.

KEY WORDS: calculus concept inventory, learning community, active learning, misconceptions

DEDICATION

I dedicate my dissertation work to my husband and children; the support and love they have given me is beyond words.

This is also dedicated to Dr. Bryan Tippett, my mentor and encouraging leader. “It does not do well to dwell on dreams and forget to live” (Rowling, 1997, p. 214).

ACKNOWLEDGMENTS

Before my acceptance into this doctoral program, I knew the topic of my research. For at least a decade, my calculus, physics, and chemistry colleagues have worked diligently with bridging gaps in student knowledge. Through working with Dr. Dwain Desbien in the learning community, I saw first-hand the information a concept inventory can give faculty about teaching and learning which inspired this research. Your insight to pedagogy pushed me outside of my comfort zone and made me a better educator.

To my committee chair, Dr. Levi Torrison, who did not let me lose track of the big picture and goal I had, I am indebted to you. You kept me on track, especially during the Covid months, and did not allow me to lose sight of my purpose with all of this. You walked me off the ledge numerous times and provided the guidance I needed. Your ability to bring together the direction and meaning of my research is invaluable. I would like to also thank committee member, Dr. Rey Rivera, for the feedback and support he provided.

This research could not have been done if it were not for the community of people who surrounded me with input and help: calculus, physics, and chemistry faculty; lab technicians; students; administrators; institutional effective office colleagues; cohort members; and friends.

Last but not least, thank you to my husband, children, parents, and mother-in-law. Your patient support and tolerance of not seeing me these past three years has not gone unnoticed. Thank you!

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CHAPTER ONE: INTRODUCTION

INTRODUCTION

According to Complete College America, of community college students, only 5% of first-time entry and full-time students complete their math courses in the first 2 years (n.d.). Research from the Mathematical Association of America found that many students who take and do not persist after first semester calculus lose their confidence and enjoyment in mathematics (Bressoud, Mesa, & Rasmussen, 2015). Hensel and Hamrick (2012) state that a majority of engineering majors do not continue due to failing out of first semester calculus. With STEM initiatives being pushed in American colleges, the mentioned math class is typically a required course in these fields of study. Unfortunately, national passing rates are low (Burn, Mesa, & Arbor, 2015). Not passing calculus thus impacts students becoming employed in STEM fields, such as engineering. Education in STEM areas is crucial to leading the next generation of new products, innovators, and critical thinkers to help sustain our economy and way of life (Eberle, 2010).

On a larger scale, in order for the United States to continue to be competitive in the global market, STEM education is in high demand. The most recent Bureau of Labor Statistics (2019) report includes occupations in fields such as statistics, mathematics, and software development as among the fastest growing professions. While those areas are in demand, students are not obtaining degrees to support these occupations. For example, from 2012-14, 35% of students who originally declared a STEM major entering college changed to non-STEM degree; mathematics majors had the highest change at 52% (Leu, 2017). In 2012, only 8.3% of community college students and 32.6% of bachelor's degrees were awarded from a STEM field (National Science Foundation, n.d.a.).

One major barrier to students obtaining a degree in STEM is first semester calculus. While calculus is crucial to understanding the applications in most STEM disciplines, this math class is considered a "weeding out" course (Rasumussen, Marrongelle, & Borba, 2014). For example, in Spring 2019, the failure and non-completion rates for students taking first semester calculus in the Maricopa Community College District (2019) in the greater Phoenix, Arizona, area was 41%. If students cannot pass calculus, a prerequisite course to many STEM pathways, then this in return blocks them from obtaining a degree.

Thus, in 1987, a colloquium on *Calculus for a New Century* was held with over 600 mathematicians, educators, and scientists (Steen, 1987). This meeting was sponsored by the National Academy of Engineering with a focus on how calculus should be a pump, not a filter, for future scientists and engineers. For the next 30 years, calculus reform was rampant and yielded very little results. So, the Mathematical Association of America (MAA) began the largest national survey to review best practices in calculus education from highly successful college calculus programs across the United States (Bressoud, Carlson, Mesa, & Rasmussen, 2013). Their findings showed student-centered pedagogies, active learning, building communities and social integration, along with consistent use of data to influence curriculum modifications, are some of the best practices.

HISTORICAL BACKGROUND OF CALCULUS AT ESTRELLA MOUNTAIN COMMUNITY COLLEGE

For the last ten years, several calculus instructors at Estrella Mountain Community College in Avondale, Arizona, have been incorporating the suggested best practices as provided by MAA, but these instructors have also been working closely with science faculty to align pedagogy and curriculum across disciplines. Both chemistry and physics instructors utilize pedagogies where students are actively engaged in small groups and, with the class as a whole, students write journals for each class period, and the instructor acts as more as a coach and not the face in the front of the room. A major goal with teaching this way is to address student misconceptions and provide a deeper level of learning of core concepts than by having students memorize facts. Several of the chemistry and physics faculties participated in, and are currently running workshops for, professional growth opportunities in the theoretical area of teaching called *modeling*. The American Modeling Teachers Association (2016) website explains this pedagogical practice by stating the following:

> The Modeling Method has been intentionally developed to correct many weaknesses of the lecture-demonstration method of instruction typically seen in STEM classrooms. These weaknesses include the fragmentation of knowledge, student passivity, and the persistence of naive beliefs about the physical world.

This way of teaching is student-centered, makes content more meaningful and relevant, and students present their thoughts and findings to each other. Through collaboration with chemistry and physics faculty, some of the calculus instructors at EMCC have incorporated similar teaching strategies and have brought in physics applications into the curriculum. Also, more of the calculus instructors now include journal writing as part of their course work. Journaling may include, but is not limited to, students explaining activities for each class period, making connections between concepts, and reflecting on what they learned and are still struggling with.

Another background piece about calculus at EMCC is that, since 2010, a fully integrated first semester calculus I and university physics I learning community has been taught between instructors. This learning community has students taking both classes together, in the same classroom, with both instructors present. Not only has this provided students with an opportunity to learn how calculus and physics intertwine, but both faculty groups are learning from each other to better align curriculum in non-learning community courses.

Historically, the learning community calculus courses have shown greater success on the EMCC common calculus final, which has more computational problems than traditional calculus classes (for data results, see Appendix A). Also, students who participate in the learning community have higher success rates in third semester calculus than those who took the traditional calculus sequence (see Appendix B). Unlike their science counterparts, calculus faculty are missing data that addresses conceptual misconceptions students may have entering and exiting first semester calculus. In order to help support student learning in physics, engineering, and other STEM courses, calculus faculty want to ensure students conceptually understand concepts to lay the groundwork for success in future courses.

BACKGROUND OF THE PROBLEM

To help determine conceptual misconceptions, faculty can use an evaluation instrument called a *concept inventory*. These tools are typically used as pre-posttests, contain multiple-choice questions, involve foundational knowledge, and are not computational (Thomas, 2013). Concept inventories do not have a common definition amongst the education world

(Epstein, 2013). So, for the purposes of this dissertation, a concept inventory is defined as a pre-post multiple choice test comprised of core conceptual questions which require no calculations. According to Ngothai and Davis (2011), “Concept inventories can be powerful tools for analyzing an individual’s conceptual understanding of fundamental concepts that underpin their core knowledge” (p. 32).

By determining misconceptions at the beginning of the semester, faculty can have students engage in different activities to address these misunderstandings. The posttest is given to provide faculty information as to how the semester’s activities addressed student misconceptions, if at all. The information can be used to modify curriculum for the following semester; this closes the assessment loop.

At EMCC, both chemistry and physics faculty utilize a concept inventory in their own disciplines. The EMCC calculus instructors have witnessed their colleagues using these tools, not only to collaborate with each other, but also to improve course activities and curriculum. Prior to 2017, EMCC calculus instructors used Epstein’s (2007) Calculus Concept Inventory (CCI) and found the CCI did not fit their needs nor provide useful information. The instrument had multiple questions with two possible answers where the first could be correct from a physics perspective and the second be mathematically correct. Epstein’s CCI also contained wording that confused students, and several questions were more appropriate for a College Algebra class. Another key problem with the tool was that it functioned more as a posttest, including complex calculus terminology, such as derivative and integral, instead of more commonplace terms, such as slope and area. Thus, students needed exposure to calculus content before having a chance to answer any pre-test questions correctly.

Epstein's CCI has been used in several studies on calculus education, but in recent years, the tool's accuracy and validity have been questioned. Unfortunately, Jerome Epstein passed away and is unable to answer the questions recently raised. In a dissertation study, Bagley (2014) did some preliminary analysis of CCI data he collected and found some problems with the instrument. While the authors and researchers of the CCI report that psychometric evaluations of the tool were conducted, Bagley (2014) mentions the following issues: validation studies have not been published; the tool does not seem to be unidimensional; distractors are not plausible-enough; and some of the questions do not differentiate low and high ability.

In a more recent article, Gleason et. al (2019) analyzed data from approximately 1,800 students and concluded that the tool lacks validity and reliability. For content validity, the authors found nine of the questions did not meet the criteria for measuring conceptual understanding of incoming calculus students due to using words and/or notation only a calculus student would know. Examples include the use of the words "derivative" and "integral," as well as calculus notation such as $f'(x)$. These are not commonsense words within students' vocabulary when beginning a first semester calculus course. After a thorough review of the CCI, Gleason et. all (2015) stated that a new CCI needs to be created because the tool "…does not conform to accepted standards for educational testing" (American Education Research Association, 2014; DeVilles, 2012, p. 1296).

Calculus faculty at several institutions have been working on writing their own CCIs. In a personal conversation with Dr. Patrick Thompson (summer 2018) and reviewing the pre-posttest used at his university, the researcher of this study found several issues with the instrument that did not fit the goals of concept inventories similar to FCI for EMCC faculty to use. Concerns with their instrument include, but are not limited to, the following:

- Several questions included calculus language
- Utilized mostly college algebra concepts
- Relied heavily on math notation and not written at a commonsense level
- Included calculations
- Completing the pre-posttest was time intensive
- Questions appeared to assess multiple concepts within one question

For example, regarding the last point, one of the questions appeared to assess (1) student's ability to understand the question as a whole, (2) student's understanding of specific vocabulary within the question, (3) math notation, and (4) how to write a formula. While the instrument was robust, included high-level questions, and fit the needs of the math faculty at the university, the tool did not meet the needs of the EMCC calculus faculty.

PURPOSE OF THE STUDY

The goal of the concept inventory (CI) developed for this study is to address misinformed foundational beliefs, as physics and chemistry faculty did with their CIs, that students may have about mathematical concepts within calculus. This research study examines several areas: (1) development of a CCI which includes conceptual misconceptions, (2) utilize the tool to improve teaching practices and activities in first semester calculus, (3) determine if students learn what is intended for them to learn, and (4) determine whether the calculus/ physics learning community addresses common misconceptions better than traditional calculus courses. Using Epstein's CCI and previous concept inventories used nationally, such as the Force Concept Inventory in physics, provide the foundation to this study.

SIGNIFICANCE OF THE STUDY

Assessing teaching strategies, different course modalities, and student knowledge and misconceptions can be difficult. Determining if students have performed the correct steps in a math problem can be simple to grade; most mathematical questions have a specific procedure to solving the problem. However, grading student's conceptual understanding and learning about misconceptions are more difficult to assess.

Thus, this study will help determine whether EMCC calculus faculties are addressing misconstructions students may have. The research will further help determine if curriculum and pedagogy alignment with physics improve student learning. And finally, this study may provide additional information for Epstein's CCI and for other calculus researchers who want to develop a nationally recognize CCI.

RESEARCH QUESTIONS

The follow research questions are at the center of this study:

1. Research Question 1 (RQ1)

Can a calculus concept inventory be written for an introductory calculus course that provides faculty with information about student misconceptions?

2. Research Question 2 (RQ2)

Was there a statistically significant difference between mean scores on the CCI among students who were in the calculus/physics learning community as compared to students taking the stand-alone calculus courses?

SETTING OF THE STUDY

The Maricopa Community College District is located in the greater Phoenix, Arizona, area and is comprised of ten individually accredited colleges. In Fall 2019, 114,775 students were attending at least one of the colleges (Maricopa Community Colleges, n.d.b.). Estrella Mountain Community College (EMCC), Gateway Community College (GWCC), and South Mountain Community College (SMCC) were included in the study.

All three colleges mentioned are Hispanic-Serving Institutions (HSIs) and include a diverse student population. Specifically, EMCC is part of the West Valley of Phoenix, and one of the only Maricopa Community Colleges with increased enrollment every year for the last 5 years (Maricopa Community Colleges, n.d.b). EMCC serves an ethnically diverse community with an average age of 23 years of age (EMCC, n.d.c.). In 2019, 10,120 students made up the EMCC population with the following demographic make-up: Hispanic 50%; White 27%; Black 11%; American Indian 3%; Asian 3%; 2+ 3%; Not Specified 3%; 68% first generation; 60% female; 39% male; and 1% undeclared sex (Maricopa Community Colleges, n.d.c).

Gateway CC, located in Central Phoenix, has 5,067 as of Fall 2019, and has the following demographics: Hispanic 50%; White 27%; Black 11% ; American Indian 3%; Asian 3%; 2+ ethnicities 3%; Not Specified 3%; 58% female; 40% male; 1% undeclared sex; and 69% first generation (Maricopa Community College, n.d.c.).

South Mountain is located in South Phoenix, serves 4,321 students and includes the following demographics: Hispanic 57%; White 15%; Black 15%; American Indian 3%; Asian 3%; 2+ ethnicities 3%; Not Specified 4%; 57% female; 40% male; 3% undeclared sex; and 69% first generation (Maricopa Community College, n.d.b.).

Each college has transfer degree offerings (associate in arts, associate in business, associate in general studies, associate in science, and associate in transfer partnership), two transfer certificates (Arizona General Education Curriculum and Academic Certificate), and two occupational awards (associate in applied science and certificate of completion) in several different areas (Maricopa Community Colleges, n.d.d).

ASSUMPTIONS, LIMITATIONS, AND SCOPE

The following assumptions were made for this study: students answered the questions to the CCI to the best of their capabilities; students voluntarily participated in the study and understood no grade inflation or special treatment would be given to them for participating; faculty did not teach to the CCI; and questions taken directly from the tool were not given in class prior to administration of the post-test.

One limitation to this study is the timeframe for the creation of the CCI. An informative and well written concept inventory takes several years, possibly up to seven or more. While the tool will start with Epstein's CCI, the new EMCC pre-posttest may need more modifications. Another limitation is that EMCC is unique in the ways that calculus, chemistry, and physics faculty work closely together. The CCI developed may be more specific to EMCC calculus faculty needs and not the greater calculus community as a whole.

As for the scope of this study, with five semesters of data being reviewed, this study included 300+ students from the three Maricopa Colleges. The estimated number of students at GWCC who participated in this study is 30; SMCC, 60; the remaining were from EMCC. The participants from SMCC came from business calculus courses and not first semester calculus for most STEM majors. The purpose of including business calculus in this population is that both types of calculus classes cover the same concepts addressed on the CCI; however, business calculus (MAT213) contextualizes content through business applications. By including MAT213 students, this study includes more input from student perspectives for wording of questions as well as a method to determine most common distractors for multiple-choice questions.

DEFINITIONS OF TERMS

Several definitions may have multiple meanings to different readers. For the remainder of this research study, the following definitions will be used for the following words:

- **Learning Community**: students taking courses together where the curriculum is intertwined – classes are taught by both instructors and fully integrated with faculty attending both courses to tag team during the block scheduling of classes
- **Concept:** an idea or understanding that stands alone
- **Concept Inventory**: pre-post multiple choice test comprised of core conceptual questions which require no calculations with each question testing one and only one concept
- **Commonsense Misconceptions** – student ideas that are different from what is accepted by scientists and mathematicians

CHAPTER SUMMARY

This chapter has provided an overview of why calculus is important in STEM fields, the collaboration efforts of calculus faculty with science instructors at EMCC, and where math faculty are lacking with determining commonsense misconceptions. An overview of how chemistry and physics uses a concept inventory to improve teaching practices was provided. The rationale as to why a CCI needs to be created was given as well as how the tool will be used for calculus instructors.

The rest of this study is broken up into four additional chapters. In Chapter Two, a literature review will be provided to show what research has been done on misconceptions, calculus education including current gaps in the research, concept inventories, and good teaching practices versus ambitious teaching. Chapter Three will describe the research design and methodology used to answer the research questions. The fourth chapter will be the findings and results of the data collected, with the fifth chapter representing the discussion of the results and recommendations for future work.

CHAPTER TWO: LITERATURE REVIEW

INTRODUCTION

Many theories have been researched on student learning and calculus education; a wide variety of literature is available. The purpose of this review is to present relevant themes found throughout literature in four key areas: (1) knowledge, including threshold concepts or misconceptions, (2) calculus education and current gaps in the research, (3) concept inventories as a tool to gauge teaching practices on addressing student misconceptions, and (4) good teaching practices versus ambitious teaching. For the purposes of this study, good teaching will be described as including the best practices previously mentioned by MAA; student-centered pedagogies, active learning, building communities and social integration, and consistent use of data to influence curriculum modifications. Ambitious teaching includes good teaching practices but also may incorporate group projects, requiring student explanations for problems, and higher percentages of active learning over lecture. How each of these areas impact this study will also be discussed.

CONCEPTUAL KNOWLEDGE

Children acquire two key types of knowledge: procedural skill and conceptual understanding (Rittle-Johson, Siegler, & Alibali, 2001). Many people look at mathematics as a step-by-step process, yet they do not understand conceptually what they are doing nor why. Rittle-Johnson et al. (2001) define procedural knowledge as a series of steps in solving a problem, while conceptual knowledge is having the ability to generalize and interrelate units of knowledge. According to Greene (2014) and Perkins (1999), a student who has conceptual understanding is one who can adapt, act flexibly with what he or she knows, and apply concepts in different ways.

In calculus education, there are typically two camps of educators: procedural versus conceptual teaching. There has been a long debate, as well as research, on whether teaching procedure versus conceptual concepts is more effective (Rittle-Johson, Siegler, & Alibali, 2001; Rittle-Johnson & Alibali, 1999; Halford, 1993). Studies show that both types of learning go hand in hand; learning is best when instructors incorporate both ways of teaching (Rittle-Johnson, Siegler, & Alibali, 2001; Rittle-Johnson & Alibali, 1999; Code, Piccolo, Kohler, & MacLean, 2014).

Research has also shown how students approach their studies (Case and Marshall, 2004; Entwistle and Ramsden, 1983; McCune, 2001) and how they learn and understand the material (Hallden, 1999; Marton and Saljo, 1976a, 1976b, 2005; Wistedt and Brattstrom, 2005) will vary from subject area to subject area (Scheja and Pettersson, 2009). Each discipline may have *threshold concepts* (Meyer and Land, 2003, 2005) that are considered transformative and lead to a new way of thinking. Meyer and Land (2003) say that threshold concepts are key ideas from courses where the content is difficult to conceptualize and sometimes considered absurd. The authors go on to provide two mathematical examples: the complex number *i* and limits from calculus.

Conceptually difficult knowledge is typically met for the first time in college science and math courses (Perkins, 1999). Everyday experiences may lead students to have misconceptions that question their ritual knowledge; their intuition and beliefs are not matching what is being taught in the classroom (Perkins, 1999; Halloun and Hestenes, 1985a; Bilici, Armagan, Cakir, and Yuruk, 2011; Desbien, 2002; Kubricht, Holyaok, and Lu, 2017). Perkins (1999) discusses how conceptually difficult knowledge is considered *troublesome knowledge*; this type of comprehension is counterintuitive and does not make logical sense to a student. Unfortunately, several core concepts from calculus are classified as troublesome.

Threshold/Troublesome Concepts in Calculus

In beginning algebra through pre-calculus, students have been instructed repeatedly that division by zero and square root of a negative number are not possible, and that two of the same numbers divided by each other is one. Yet, when students reach calculus, all of these deep-seated mathematical concepts are challenged. Some examples of calculus concepts introduced to students include how to deal with the concept of infinity, division by zero using infinitely small increments, and summing an infinite number of items to arrive at a single value; students conceptually struggle with these ideas. Research on how to help calculus students gain a deeper understanding of these difficult concepts has occurred throughout the decades.

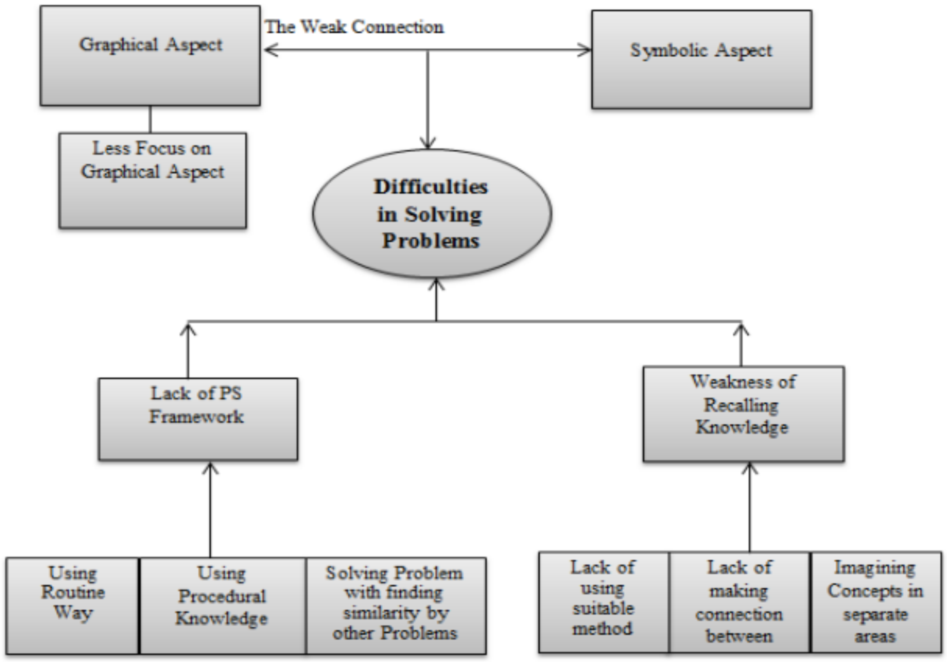
Rasmussen, Marrongelle, and Borba (2014) wrote a survey paper on the history of research in calculus education including any gaps of what has been studied. The authors write:

> Research on calculus learning and teaching generally has followed a pattern of (1) identifying and studying student difficulties and cognitive obstacles followed by (2) investigations of the processes by which students learn particular concepts, (3) evolving into classroom studies (or close approximations thereof), including the effects of curricular and pedagogical innovations on student learning, and, more recently (4) research on teacher (including graduate student instructor, lecturers, etc.) knowledge, beliefs, and practices. (p. 508)

For the first area of research mentioned above, studies show that three core concepts within calculus where students have misconceptions includes limits (Kula and Guzel, 2014; Davis and Vinner, 1986; Tall and Vinner, 1981), derivates, and integrals (Hashemi, Abu, Kashefi et al., 2015; Rasmussen, Marrongelle, and Borba, 2014; Orton, 1983a, 1983b). The concept of *limit* lays the foundation for derivatives and integrals, along with introducing students with how to deal with division by zero. For limits, not only can the terminology used by instructors be misleading to students (Cornu, 1991; Monoghan, 1991; Frid, 1994; cited in Kula and Guzel, 2013), but so does the idea of the value of a limit not being reachable (Juter, 2005; Tall and Schwarzenberger, 1978; Williams, 1991; Nair, 2010; as cited in Kula and Guzel, 2013). Orton (1983a) found that students struggled with understanding how a limit of a secant line becomes a tangent line. Limits involving infinity and infinitesimals are the cornerstone concept that led to sequence convergence, derivatives, and integrals (Bressoud, Ghedamsi, Martinez-Luaces etc al, 2016).

Researchers (Stacey, 2006; Metaxas, 2007; Tall, 2012; as cited in Hashemi et. al, 2015) found that students struggle with the symbolic and graphical representations of derivatives and integrals. Lack of prior knowledge also leads to difficulties with interpreting, understanding, and performing these concepts (Polya, 1988; Tall and Yudariah, 1995; Tall, 2001, 2004a, 2007; Kirkley, 2003; Villers and Garner, 2008; Mason, 2010; Tarmizi, 2010; as cited in Hashemi et. al, 2015). In the figure found below, a visual representation of the areas where students have weaknesses with derivatives and integrals is provided.

Figure 1. Difficulties in solving derivates and integrals.



Reprinted from Hashemi, N., Abu, M. S., Kashefi, H., Mokhtar, M., & Rahimi, K. (2015). Designing learning strategy to improve undergraduate students' problem solving in derivatives and integrals: A conceptual framework. Eurasia Journal of Mathematics, Science and Technology Education, 11(2), 227–238.

Theories on how students learn has been a main focus in calculus education, and there is a gap in reviewing the misconceptions students may have coming into a course (Rasmussen, Marrongelle, & Borba, 2014). Thus, this is a major part of this dissertation study; the researcher will be investigating commonsense misconceptions students have and developing a calculus concept inventory.

CONCEPT INVENTORY

The concept inventory discussed in this document will be modeled on the work done by Halloun, Hestenes, Wells, and Swackhammer (1985a, 1985b, 1992) and Epstein (2007). In the

1980s, physics faculty from Arizona State University developed an assessment tool, called the Mechanic Diagnostic Test (Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b), to determine what commonsense misconceptions students had about physical phenomena such as motion and force. The diagnostic test is not computational and has been used to show that conventional instruction does not address student misconceptions pertaining to physics concepts (Desbien, 2002; Laws, 1991; Van Heuvelen, 1991; Halloun and Hestenes, 1985b). The tool led to the development of what is now called the Force Concept Inventory (FCI) and is worded using plain language that is easily understandable by students in first semester university physics courses (Saul, 1998). The simplicity of the FCI made professors, such as Eric Mazur, physics faculty at Harvard, think the assessment tool was too simple (Saul, 1998).

Saul (1998) quotes Mazur,

> …I taught a fairly conventional course consisting of lectures enlivened by classroom demonstrations. I was generally satisfied with my teaching— my students did well on what I considered difficult problems and the evaluations I received from them were very positive. As far as I knew there were not many problems in my class. (p. 17)

Mazur, like many other physics faculties, found that students struggled more with the simple conceptual problems rather than the traditional conventional problems. Mazur learned that his lectures did not address the conceptual commonsense misconceptions of students.

Thus, the FCI has been used to inform instructors how their teaching practices influence students' thoughts and ideas of threshold and troublesome concepts, such as motion, within their physics course (Halloun and Hestenes, 1985a; Hestenes, Wells, Swackhammer, 1992; Desbien, 2002).

With the findings of the FCI, The National Science Foundation (e.g., n.d.b, n.d.c, n.d.d) has funded several grants to improve physics education. Several other fields, such as engineering, astronomy, and calculus, have created concept inventories to try to have the same impact on teaching and learning (Thomas, 2013; Ngothai & Davis, 2011; Bilici, Armagan, Cakir, & Yuruk, 2011; Epstein, 2007).

In Spring 2004, Epstein (2013) and Yang were awarded an NSF grant to develop and validate a calculus concept inventory (CCI). Epstein believed that developing a CCI would help bridge the divide between skill-based instruction and those who believed in guided discovery. He argued that the CCI was an attempt at getting the calculus world to agree upon core concepts students should know in a first semester course. As stated before, Gleason, Bagley, and Thomas (2019) found that this tool lacked reliability and validity; thus, a new CCI needed to be developed. With the creation of a new CCI for EMCC, calculus faculty will use the tool to review gains on the CCI in within calculus courses and review pedagogies within each course.

GOOD TEACHING VERSUS AMBITIOUS TEACHING

Studies show that calculus courses where faculty incorporate science labs, group work, and conceptual exploration will have higher success with student engagement and understanding (Dibbs, Glassmeyer, & Yacoub, 2013). Unfortunately, all these best practices for a calculus classroom will still have students leave the course with the same misconceptions they had as when they entered the class (Dibbs, Glassmeyer, & Yacoub, 2013).

Sponsored by the National Science Foundation (NSF), The Mathematical Association of America (MAA) conducted a national study from 2009-14 on *Characteristics of Successful Programs in College Calculus* (MAA, 2015). This 169-page report reviewed student attitudes, placement, curriculum, academic and social support, and several other areas in calculus at the university and community college level. This thorough study found the following characteristics for good teaching of calculus:

- Incorporate more higher order thinking assignments which address misconceptions
- Increase questioning and engagement in the classroom that also involve higher-order thinking
- Create an environment where students are comfortable asking questions
- Stay positive when students make mistakes and be available to students
- Create realistic high and clear expectations of students
- Create an environment where students are engaged with the material

Ambitious teaching includes instructor characteristics of utilizing group projects, requiring explanations for answers, stressing active learning over lecture, and including unfamiliar problems on exams and homework (MAA, 2015). This style of teaching is typically called *student-centered instruction*. Lampert, Beasley, Ghousseini, Kazemi, and Franke (2010) define ambitious teaching as pedagogy that develops conceptual understanding, adaptive reasoning, procedural fluency, and strategic competence (as cited in MAA, 2015). Students interact with each other and the instructor, as well as explain concepts to each other including their rationale. The MAA report cites several studies that show active learning and student-centered instruction supports conceptual learning gains (e.g., Kogan & Laursen, 2013; Kwon, Rasmussen, & Allen, 2005; Larsen, Johnson, & Bartlo, 2013).

Freeman et al. (2014) conducted a meta-analysis of 225 studies between lecture and active learning STEM courses; student performance on concept inventories increased by 0.47 standard deviations in active learning courses. The MAA (2015) report does state that ambitious instruction does depend primarily on the instructor. If a calculus program wants to have a large offering of calculus courses that involve student-centered instruction, then training programs and smaller class sizes are important.

As previously mentioned in this document, an ambitious teaching pedagogy is used in several chemistry and physics courses called modeling. A modified version of modeling instruction is predominately used in physics and chemistry called modeling discourse management. This teaching methodology was first introduced by Desbien (2002) in his dissertation study. With modeling discourse management, students work in small teams on an activity, then they circle as a large class and discuss the findings within each small group. The instructor asks questions and does not provide information, except when needed.

Desbien's findings showed that by having a larger class discussion in addition to small group discussion, students had higher gains on the Force Concept Inventory in courses that utilized modeling discourse management. Since 2002, Desbien has been using modeling discourse management in his own physics courses and has worked with chemistry and some calculus faculty to incorporate this into their own classrooms. Since 2010, with the start of the calculus/physics learning community, more calculus faculty have begun to use more student-centered teaching practices.

LEARNING COMMUNITY

A learning community (LC) typically involves students taking courses together where the curriculum is intertwined. For example, an English and History class may be designed so that all papers for English are written to address content within the History class. These communities bring together participants who work together, learn from and support each other, and build a sense of belonging (Harvard University, 2019). Within a school environment, a LC also builds knowledge across content areas and may be offered in different formats such as the following:

- Linked – two or more courses with a common theme and the same set of students — instructors are not present for each other's class
- Integrated – similar to linked format, but classes are fully integrated with the faculty attending all courses to tag team during the block set of classes
- Living – students take the same courses together but also live in the same residence hall

Learning communities typically have three things in common: shared knowledge, shared knowing, and shared responsibility (Tinto, 2003). Lardner and Malnarich (n.d.) stress: "The camaraderie of co-enrollment may help students in school longer but learning communities can offer more: curricular coherence; integrative, high-quality learning; collaborative knowledge-construction; and skills and knowledge relevant to living in a complex, messy, diverse world" (p. 1). A well created and implemented learning community continually has interaction and collaboration between community members as they work towards a common goal (Lenning et al., 2013). Curriculum is aligned for coherence and to increase interaction between faculty and students (Gabelnick et al, 1990; Smith & Hunter, 1988).

The Center for Community College Student Engagement (2013) explores high impact practices that enhance and/or improve student success. In a report supported by the Bill and Melinda Gates Foundation and the Carnegie Foundation for the Advancement of Teaching, four different surveys were reviewed: the Survey of Entering Student Engagement (SENSE), the Community College Survey of Student Engagement (CCSSE), the Community College Faculty Survey of Student Engagement (CCFSSE), and the Community College Institute Survey (CCIS) (Center for Community College Student Engagement, 2013). One of the mentioned high impact practices include learning communities; participation in these types of courses show a high positive relationship in *active and collaborative learning*, *student-faculty interaction*, and *support for learners*.

In a research study done by Tinto et al. (1994), the researchers found that students in learning communities learned more due to forming their own support groups, both academically and socially. The culture within the learning community promoted seamless learning from two or more instructors, and students built strong relationships with others. In a three-year study that reviewed 19 institutions, called the National Learning Communities Dissemination Project, the findings showed students who participated in LCs had the same or higher grades than those who took traditional stand-alone courses (Minkler, 2002).

At Daytona Beach Community College, Florida, researchers measured cognitive development of students who participated in an interdisciplinary learning community program (Minkler, 2002). In an essay-writing instrument measuring cognitive complexity called the Measure of Intellectual Development by Knefelkamp and Widick, and through another measurement tool called Perry's scheme of intellectual development in the college years, students from the LC had greater gains on these instruments as compared to traditional students (Avens & Zelley, 1992: as cited in Minkler, 2002). Rings et al. (1999) also showed the same results, using the same assessment, for LCs done within the Maricopa Community Colleges. Overall, studies find that students who participate in well structured, organized, and collaborative learning communities will have higher gains in learning and personal development (Taylor et al., 2003; Kuh, 2008). It is important to note, as stated by Reiss (n.d.), that just because a learning community is offered, this does not mean learning outcomes will be met; how the LC is implemented is important.

SUMMARY

The literature review focused on common misconceptions students have entering and exiting a course, and how these beliefs students hold may not be addressed during the course (Perkins, 1999; Halloun and Hestenes, 1985a; Bilici, Armagan, Cakir, and Yuruk, 2011; Desbien, 2002; Kubricht, Holyaok, and Lu, 2017). Different courses will have different threshold concepts, and calculus ones include limits, derivatives, and integrals (Hashemi, Abu, Kashefi et al., 2015; Rasmussen, Marrongelle, and Borba, 2014; Orton, 1983a, 1983b). One tool to assess misconceptions is through a concept inventory, and the literature showed there is a need to develop a new CCI (Gleason, Bagley, & Thomas, 2019).

The literature review also examined good teaching versus ambitious teaching and what this looks like in a classroom. Student-centered teaching typically has higher conceptual gains (Kogan & Laursen, 2013; Kwon, Rasmussen, & Allen, 2005; Larsen, Johnson, & Bartlo, 2013). If implemented properly, learning communities are one way to bring in student-centered instruction, building community and relationships amongst faculty and students, and create an environment with deeper levels of learning (Reiss, n.d.; Taylor et al., 2003; Kuh, 2008).

With some calculus instructors at EMCC using more ambitious teaching methods, including teaching in a calculus/physics learning community, in their classrooms, the development of a CCI will provide data to math faculty to further discuss whether these activities show higher gains on the CCI.

CHAPTER THREE: METHODOLOGY

INTRODUCTION

Pre-posttest designs can be used to obtain baseline information about a group, provide an intervention, and an opportunity to determine how the intervention impacted the group (Dimitrov & Rumrill, 2003). This study explored the creation and use of a calculus pre-posttest that provided calculus faculty insight into student misconceptions. The tool was used to review what students knew coming into a course and to see how different calculus courses may or may not have addressed these commonsense misconceptions. The calculus courses included traditional first semester calculus, learning community between first semester calculus and physics, and business calculus. This methodology chapter provides an overview of the research design as to how a CCI was developed for calculus faculty, with the help of two other Maricopa colleges at Estrella Mountain Community College. How the tool was used to review different types of courses will also be reviewed. Information about the study, including who participated, a timeline, research design, methodology, data collection, and type of data analysis will be discussed.

RESEARCH QUESTIONS

This quasi-experimental research study explored the following research questions:

1. Research Question 1 (RQ1)

   Can a calculus concept inventory be written for an introductory calculus course that provides faculty with information about student misconceptions?

2. Research Question 2 (RQ2)

Was there a significant difference between mean scores on the CCI among students who were in the calculus/physics learning community as compared to students taking the stand-alone calculus courses?

Hypothesis for RQ2

H_0: For students who completed first semester calculus/physics learning communities, there was no significant difference in the mean scores on the CCI versus students who completed first semester stand-alone calculus courses.

Alternative Hypothesis for RQ2

H_1: For students who completed first semester calculus/physics learning communities, there was a significant difference in the mean scores on the CCI versus students who completed first semester stand-alone calculus courses.

SETTING, PARTICIPANTS, AND TIMELINE

The study took place within the Maricopa Community College District in the greater Phoenix, Arizona, area. As previously discussed, three of the ten Maricopa Colleges, that have similar demographics, partook in data collection: Estrella Mountain Community College (EMCC), Gateway Community College (GWCC), and South Mountain Community College (SMCC). The study began at end of Fall 2017 and continued through Spring 2020, spanning five semesters. Since courses last one semester, the student participants in the study varied each term. The CCI was administered in several courses: MAT220, MAT221, or MAT213. Students who volunteered for interviews came from MAT220 (five-credit calculus I), MAT221 (four-credit calculus I), MAT213 (four-credit business calculus), MAT230 (five-credit calculus II), MAT231 (four-credit calculus II), MAT241 (four-credit calculus III), or MAT276 (four-credit differential equations). For course descriptions and competencies, see Appendix C.

The faculty involved in the review and creation of the CCI included two GWCC math faculty, four SMCC math faculty, four EMCC math faculty, three EMCC physics faculty, and three EMCC chemistry faculty. In the first draft version of the CCI, thirteen EMCC calculus I and twelve EMCC calculus II students took the test in December 2017. Eleven EMCC students from calculus I, II, and differential equations participated in interviews in that same month. Only the posttest was administered to give initial feedback on the first draft CCI created by faculty.

Using the information from the previous semester, Spring 2018 students in calculus I and business calculus took the second draft of the CCI during class; it was completed during the first week of classes and the week before finals. Students in courses ranging from first, second, and third semester calculus, differential equations, and business calculus participated in separate interviews and/or provided written rationale as to why they chose the answer they did. To continue determining common distractors, faculty gave homework with no multiple-choice options. In addition, 79 in-class assignments were collected and organized from EMCC (61 students) and SMCC (18 students).

The number of students who participated in the Spring 2018 data collection are as follows:

- EMCC: four faculty; 83 students from MAT220; 14 students from MAT221; eight were interviewed; 17 wrote their rationale while taking the CCI
- GWCC – one faculty; 24 students from MAT220; none were interviewed but two wrote down their rationale for the faculty member
- SMCC – one faculty; 26 students from MAT213; none were interviewed but 14 of 26 wrote down their rationale for the faculty member

Due to time commitments, GWCC no longer participated in the study after Spring 2018. Thus, Fall 2018 participants for EMCC and SMCC (Table 1), included faculty who administered the CCI, students who took both the pre- and posttest, students who participated in interviews, those who submitted assignments, and those who provided written rationale while taking the CCI.

Table 1: ***Fall 2018 Number of Participants for Each Data Collection Process***

College	Faculty Participants	Pre-Posttest Scores	Student Interviews	Assignments	Rationale
EMCC	6	MAT220: 92 MAT221: 33	8	81	32
SMCC	1	MAT213: 17	0	0	2

By end of fall 2018, math, physics, and chemistry faculty from EMCC followed up with the researcher to review the final draft of the CCI that would be used for research question 2 (RQ2).

In both Spring 2019 and Fall 2019, the CCI was not changed, but student rationale for selecting certain answers was still given for two faculty members at EMCC. Also, only EMCC calculus classes were used due to not having pre-post data for SMCC in Fall 2019. Second, since RQ2 focuses on comparing students who take the calculus/physics learning community instead of the traditional path of first calculus before completing physics, this was the other rationale to excluding SMCC (including students from MAT213 for analysis on the CCI will be further discussed in Chapter Five). Table 2 provides the number of faculty who administered the CCI, students who took both the pre- and posttest, and students who provided written rationale while taking the CCI.

Table 2: ***Spring 2019 – Fall 2019 Number of Participants for Each Data Collection***

College	Participating Faculty	Students completing Pre- / Posttests	Rationale
EMCC – Spring 2019	5 (4 of these participated in Fall)	MAT220 – 65 MAT221 – 27	32
EMCC – Fall 2019	5 (1 new participant)	MAT220 – 71 MAT221 – 32	14
Total	5 distinct faculty members	MAT220 – 136 MAT221 - 59	46

In Spring 2020, 12 students provided interviews on select questions from the CCI. In summary, over a five-semester span, 15 different faculty provided input and/or participated in administering the CCI, 39 students were interviewed, 160 student assignments were collected, 113 rationales were collected, and 470 students took the pre-posttest.

RESEARCH DESIGN

This quantitative study is a quasi-experimental and nonequivalent group design. Trochim (2020) describes quantitative data as one that can be categorized numerically, and quasi-experimental studies are ones where participants are nonrandomized. Students from schools with similar demographics who took calculus will be part of the pre-posttest study. Since the groups cannot be guaranteed as comparable, yet they are similar, then this is classified as a nonequivalent group design (Trochim, 2020). No control group was used since all classes that gave the CCI had calculus instruction as an intervention. Thus, only comparison groups were included in this study.

After reviewing *Development and Validation of Instruments to Measure Learning of Expert-Like Thinking* by Adams and Wieman (2010), the research design of this study follows their recommendations. The research report discusses how to develop a *Formative Assessment of Instruction* (FASI). The authors discuss creating tools such as the FCI and how others can develop similar ones to provide information as to how instruction impacts student learning. Thus, the following is a description of their recommendations and will be followed for this research design.

Adams and Wieman Framework

In order to impact instruction through the use of a pre-posttest, four practical requirements to the tool are described: (1) Instructors should be able to give the instrument in as a pre-posttest (not one or the other); (2) the tool should be easy, no training needed for the faculty member, to administer during designated class time and easy to grade; (3) the instrument should provide value to the instructor; and (4) the tool measures what it claims to measure.

Since the primary goal of instruments similar to the CCI is to be a formative assessment of teaching, then the results of the student group as a whole are more important than the individual student analysis. Including student interviews is essential for both the development and validation. Statistical item analysis, i.e., analyzing individual questions, takes a back seat to student interviews. The authors emphasize that student interviews provide more information about validity of questions. In order to keep the ease of administering and grading FASI, and to be consistent through eliminating interrater reliability issues, multiple-choice or Likert-scales are preferred. The authors also recommend having students take conceptual FASI during class and not online.

The final phases of the development of the tool include the following, as stated by the authors:

> (1) Establish topics that are important to teachers (in our case, college or university faculty members). (2) Through selected interviews and observations, identify student thinking about these topics and the various ways it can deviate from expert thinking. (3) Create open-ended survey questions to probe student thinking more broadly in test form. (4) Create a forced answer test that measures student thinking. (5) Carry out validation interviews with both novices and subject experts on the test questions. (6) Administer to classes and run statistical tests on the results. Modify items as necessary. (p. 6)

How a FASI is administered is also important; students need to take the assessment seriously. The authors recommend not counting the assessment towards their grade, and to administer the instrument in the first and last week of school (not during finals week). Instructors who did the following had students take the FASI more seriously. Instructors encouraged students to select the best answer as to what they believed to be correct, do not dwell on the question if they do not know, and finish the assessment. Instructors also informed students that the tool would be used to improve instruction.

While item analysis was discussed in the research article, this dissertation study will be focusing on student group data, as suggested by the authors, over question-by-question analysis. Item analysis is provided in the appendices, and Chapter Five will discuss future analysis, such as point biserial correlation, to enhance the CCI.

To summarize, this research study did the following based off of the given recommendations: CCI was written as a multiple-choice pre-posttest; worked with instructors on topics they viewed as important to be included on the tool; collaborated with faculty to develop questions; gave open ended homework assignments to students to determine top distractors for multiple choice questions; interviewed students each semester to improve wording of questions along with determining rationale to answers; modified CCI based off of student feedback; kept data collection of CCI simple by providing student answer sheets in form of bubble sheet; kept time to take CCI under 45 minutes; CCI was given the first week of the semester and week before finals for all participating courses; used scanner to grade pre-posttests; did not use CCI for student grades; compared MAT220 to MAT221 courses; followed up with faculty about data results from CCI.

DATA COLLECTION PROCESS

Developing the CCI

To address RQ1, two phases occurred and are discussed below.

Phase One: Writing Questions. This study utilized a variety of data collection techniques. First, in developing questions for the CCI, an email was sent to calculus faculty throughout the Maricopa Community College District (see Appendix D), and those who responded participated in the study. The researcher traveled to GWCC and SMCC to interview volunteer faculty to review Epstein's CCI and develop new questions. Faculty at EMCC met with the researcher either individually or as a group to review the questions. Faculty were given a hard copy of Epstein's CCI. Each question was reviewed, edited, and alternative questions were sometimes given from each group. During each college input session, the researcher handwrote suggestions and edits onto a copy of Epstein's CCI (one for SMCC, GWCC, and EMCC). These handwritten notes were then transferred to a Word document to be reviewed for common themes between faculty and different colleges. For each semester which faculty gave feedback on the latest version of the developed CCI, the same process was followed.

Phase Two: Wording and Distractors. Next, to aid in determining plausible distractors for CCI questions, over three semesters, six faculty volunteers who helped in writing questions gave non-graded assignments to students that included developed CCI questions. These questions were written as open-ended questions, collected by the instructor, and sent to the researcher. Student work was then transcribed into an Excel spreadsheet to be reviewed for common distractors.

The answers were labeled at the nominal-level and labeled as 1, 2, 3, etc. For example, one of the questions on the CCI asks students to draw the graph of the derivative given the original function. Graphs drawn by students that are similar were grouped together and given a label. This process occurred with several of the questions.

The second process with determining plausible distractors occurred while conducting interviews with students. Faculty were asked to recruit volunteers from their courses to participate in interviews. Faculty were asked to announce in their classes about the interview opportunity; any interested students either contacted the researcher through email or in person. All interviews held on the EMCC campus occurred in a designated space on campus. Due to conflicting schedules, no interviews with students occurred at SMCC or GWCC. But participating faculty members at these colleges did have students volunteer to provide their rationale to their choice of answers and include input about question wording.

During the EMCC interviews, students took the CCI and wrote down their rationale as to why they believed their answers were correct. After taking the CCI, students reviewed their explanations with the researcher to make sure the researcher understood the written details. In a process similar to the homework assignment process, the written rationale was categorized in an Excel spreadsheet and labeled at the nominal level. Common answers were grouped together and labeled with 1, 2, 3, etc.

The final part of the interview was to receive feedback about the wording of the questions. The goal of the qualitative feedback was to verify each question was testing only one concept and was worded clearly for student understanding. These results were also categorized in Excel using a similar nominal process as previously mentioned. If students were confused by the question, this confusion should have been due to the concept within the question and not because of the wording. All students were assigned a number to remain anonymous.

Finally, two questions within the CCI included follow up questions for students to choose their reasoning for selecting a specific answer. For example, once students answered question three, the fourth question asked why they chose their answer.

Overall, the CCI developed for this study was a three-semester process from Fall 2017-Fall 2018. The tool was modified each semester after posttest results and interviewing students and faculty. Note that each semester, the same students received the same pre- and posttest with no changes to the tool; only modifications were made after posttests were scored and based on student interviews/rationale.

Phase Three: Administering CCI. After the CCI was developed, the tool was administered with no changes in Spring and Fall of 2019. While student interviews and rationale were still collected, no modifications were made based on the information. This version of the instrument was used to answer RQ2.

In dispensing the CCI, faculty volunteers were given bubble sheets and copies of the CCI for each student in their classes. Students were informed that CCIs were not for a grade but only for informational purposes for the faculty member. Bubble sheets were given to the researcher who passed them onto the lab technicians who used a Gravic scanner that operates Remark Software. This scanner grades the bubble sheets, generates a report of the pre-posttests, and lab technicians email the document to the participating faculty member.

Data collected on these sheets include instructor name, semester, course number, and categorizing the test as pre- or posttest. The software also calculated additional data that will be discussed in the next section. For these purposes of this research study, all student names were removed from data analysis for anonymity.

Only four of the participating faculty volunteers were willing to give additional class time for students to write down their rationale as to why they chose the answer they did. These notes were made on blank paper, given to the researcher, and transcribed into and Excel spreadsheet using the same process in phase two.

DATA ANALYSIS TECHNIQUES

RESEARCH QUESTION ONE (RQ1)

Faculty and student interviews and documented rationale through the previously mentioned nominal process were the crutch for addressing RQ1. To further address RQ1, the Cronbach Alpha ($\propto$) statistic was used to calculate reliability, or internal consistency, on the CCI. This formula yields a value between zero and one and was designed to be used for two-way data where rows are represented by people and columns include two or more scores from a test (Cronbach and Shavelson, 2004). This aligns to the CCI which includes student participants, a pretest score, and a posttest score.

The formula for Cronbach ∝ is given by Equation 1:

$$\propto = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}} \qquad (1)$$

with N = number of items; $\bar{c}$ = average covariance between item-pairs; and $\bar{v}$= average variance of each term (University of Virginia Library, 2020).

Low Cronbach alphas may be reasonable due to the length of the CCI, and a higher alpha may not mean one has a reliable test but instead, the tool may have too many redundancies (Adams and Weiman, 2010). According to Taber (2018), "A wide range of different qualitative descriptors was used by authors to interpret alpha values calculated" (p. 1278). In science education journals, one author may claim 0.75 as a reasonable value while another author may say anything above 0.65 is good. Through Taber's (2018) review of a multitude of research articles, a value near 0.7 or above is widely determined as desirable and will be used in this study.

Research Question Two (RQ2)

With the data and experimental design, descriptive and comparative data analysis were completed. Visual representation of each data set is provided through the use of histograms that include frequency of the following: pretest scores, posttest scores, difference between pre- and posttest scores, and Hake Gain scores. A one-way ANOVA was calculated to determine existence of a significant difference between the learning community CCI and traditional calculus courses. Only student scores for which there is both pre and posttest score were used in the data samples.

The normalized gain, or Hake gain (Hake, 1998), was calculated for each student using their pre-posttest scores. Hake gain is typically used on concept inventories to denote the measure of change in scores prior to instruction to post-instruction and is used to gauge student learning (Coletta & Steinert, 2020). This value, Equation 2, is calculated by

$$g = \frac{Post\ score - Pre\ score}{23 - Pre\ score} \qquad (2)$$

where 23 is the number of questions on the CCI. Comparison of means was used in the SPSS statistical software.

Additional analysis of the data was completed within the learning community classes. Six faculty members in total taught in the learning community over the two-semester period: four math and three physics faculty. Three of the four math faculty and one physics faculty were newer to this teaching environment. These faculty had only one to four semesters of experience teaching in MAT221-PHY121 while the other faculty members, including two of the physics faculty, had eight or more semesters' each of experience. It is important to note that the one calculus faculty with 12+ semesters' of experience in the learning community, having taught with three different physics faculty, is this dissertation's author. Two calculus-physics learning communities were offered each semester, and three of the four courses were led by newer faculty.

The less experienced faculty were not only learning how to incorporate physics and calculus seamlessly, but they were also being exposed to a new way of teaching using ambitious teaching methods. As a reminder, ambitious teaching involves pedagogy that utilizes student centered learning, developing conceptual understanding, adaptive reasoning, and contextualized learning. A deeper dive of the MAT221 CCI data will be provided to review whether experience may be a factor in comparing MAT220 to MAT221.

RELIABILITY AND VALIDITY

To reduce threats to validity, multiple processes were followed. First, the CCI was reviewed to determine whether the test measures what it is claimed to measure. To address face validity, student and faculty interviews, along with using student rationale and assignments, were key in developing the instrument. In regard to content validity, 15 different faculty members from varying content areas reviewed the CCI and provided suggestions to questions and common distractors. Second, students from calculus II, III, and differential equations also reviewed the tool and agreed upon the most appropriate answer while also reviewing the question wording. Third, 38 student interviews were conducted to ensure that students understood the wording of the questions and identify top distractors.

The Cronbach alpha score will either confirm or deny internal consistency (reliability). Other ways to reduce threats to reliability include (1) the same students (each semester) taking both the pre- and posttest, (2) a majority of the faculty participants giving the CCI each semester being the same, and (3) questions in the last two semesters not changing.

LIMITATIONS

Pre-posttest designs have higher internal validity over external validity. In this research design, it is ethically irresponsible to have a control group with no intervention (teaching). So, there is no baseline data to compare with. Other limitations include different students each semester; risk of faculty teaching to the CCI; students and faculty not taking CCI seriously; and students self-selecting into the calculus courses, especially the learning community.

SUMMARY

As noted in the literature review, there is a need for a CCI in the calculus community. This study has laid groundwork through collaborating with faculty, interviewing students, and using student work to create a CCI. Once the tool was developed, it will be used in a first-round comparison of calculus courses. This will address the second research question of whether there was there a statistically significant difference between mean scores on the CCI among students who were in the calculus/physics learning community as compared to students taking the stand-alone calculus courses. The outcome of the research has a potential to influence discussions at national conferences around the development of a nationally recognized CCI.

CHAPTER FOUR: DATA RESULTS AND ANALYSIS

INTRODUCTION

This chapter is separated into two parts with subsections. The first section presents the results of the analysis of the quantitative data pertaining to the creation of the CCI through faculty interviews, student interviews, and student assignments. The second section presents the findings of the analysis of the quantitative data of the comparison between averages on the CCI between learning community students and traditional calculus students. As a reminder, MAT220 is traditional calculus while MAT221 is linked with physics in the learning community.

Review and analysis of these data sources provided insight in answering the two research questions:

1. Can a calculus concept inventory be written for an introductory calculus course that provides faculty with information about student misconceptions?
2. Was there a significant difference between mean scores on the CCI amongst students who were in the calculus/physics learning community as compared to students taking the stand-alone calculus courses. For research question two, $\propto < 0.05$ for rejection of the null hypothesis was used in the comparison of the groups.

RESEARCH QUESTION ONE

Can a calculus concept inventory be written for an introductory calculus course that provides faculty with information about student misconceptions?

First Draft: Fall 2017

In the initial development of the CCI, faculties from EMCC (four math, two physics, and two chemistry), SMCC (four math), and GWCC (two math) reviewed Epstein's CCI and were able to come to consensus on the first draft. Common themes from Epstein's CCI emerged through faculty interviews and can be found in Appendix E.

Eight questions remained from Epstein's CCI with slight modification and fourteen new questions were developed. Thirteen calculus I and twelve calculus II students from EMCC took the first draft CCI to provide initial feedback. The information gathered included how long it took for students to take the assessment, review wording of questions, locate typo errors, and determine whether there was a potential missing distractor. Students finished between 35-45 minutes with an average of 42 minutes. In order to determine whether to modify a question based on feedback, the following thresholds were used:

- Three or four students had same issue with a question: The question was not modified but catalogued on a watch list the following semester.
- More than four students having same issues with question: The question was modified using student feedback.

After the interviews were completed, five questions were modified, one question was put on the watch list, and one typo was found and corrected. Table three includes a summary of the modified/watch list CCI questions.

Table 3: Theme-related Issues/Concerns of Specific CCI Questions and Results

Question Number(s)	Issue/Concern	Result
15	"What is required of 'a' and 'b'…" more than 15% of students kept reading the variable 'a' as the word 'a'; students suggested changing the letters used in problem.	Letters were changed to 'c' and 'd'
8, 12, 13, 22	Students said graphs were not clearly labeled and hard to read.	Maple, a mathematics software, was used to draw one of the graphs; two of the graphs were relabeled; the last graph added the wording "interval" to the question, so students knew what portion of the graph to read.
18	The question uses both the words "integral" and "interval"; these words are similar / easily confused. Students were reading fast and became confused thinking they read the same word twice. Students had to re-read the question several times; they gave recommendations on how to modify the wording.	No modifications were made, but this question was put on the watch list.

EMCC faculty updated the CCI, and the second draft was sent to GWCC and SMCC faculties for review. This new draft was approved and given in Spring 2018.

Second Draft: Spring 2018

In Spring 2018, a full round of the pre-posttest was given. For this round, 147 students took the pre-posttest, 19 students were interviewed, 33 students provided rationale to their answers, and 79 in-class assignments were collected. Both interviews and assignments were used to modify the CCI for the third draft. Specifically, the assignments were examined for common distractors for two questions (graphing derivative and a question regarding the concept of 0/0). The Cronbach Alpha score on the CCI was 0.40, which is not considered a reliable assessment.

Third Draft: Fall 2018

Summer of 2018 drastically changed how the researcher understood the CCI through an interview with Dr. Spencer Bagley. While the summer was originally going to be used to review Spring 2018 interviews, explanations, and assignments for common themes, the interview with Bagley changed the course of the CCI. After reviewing several calculus articles written by Dr. Chris Rasmussen, especially "MAA Calculus Study: Seven Characteristics of Successful Calculus Programs," the researcher contacted Rasmussen to ask for guidance on the pre-posttest. Rasmussen connected this researcher with Bagley, who has authored several articles about why a new CCI needed to be created. In June 2018, Bagley met virtually with the researcher to discuss the EMCC tool.

Bagley emphasized the need to ensure a more common sense CCI is created that can be used as a pre- and posttest, not just posttest. After speaking with Bagley, he emailed detailed feedback on each question. Spencer (personal communication, July 18, 2018) wrote, "Overall comment: I think this is a really good *post-test* — I like the overall aim of getting people to link vocabulary words with their actual calculus meanings. I just think it won't work as a pre-test, because you'll get an artificial gap between the performance of people who know vocabulary words vs. people who don't." This statement, along with his feedback on each question, changed the trajectory of the CCI.

The Bagley interview brought the researcher and faculty at EMCC to a crossroads and finally triggered with the researcher what a "common sense calculus concept inventory" really meant. While the researcher was building from Epstein's CCI, which included questions that met faculty goals including alignment to physics, the second draft of the CCI continued to use terminology that only a student exposed to calculus would know. Did EMCC faculty want to create a really good posttest, or revamp the tool to meet the original goals of the assessment? The purposes of the CCI includes to assess student logic and thinking, review calculus from a commonsense level, and determine whether students had a deeper level of understanding of calculus through contextualized learning. Faculty agreed to greatly modify the pre-posttest to align to the original goals.

First, each question from the Spring 2018 CCI was reviewed for ways to rewrite the question without using calculus language. Desbien, a physics faculty member at EMCC, was instrumental in modifying the Spring 2018 questions to exclude calculus language. With physics and calculus so closely aligned at EMCC, especially within the learning community, several physics-based questions were modified with a calculus twist. For example, in physics, questions that include words such as "velocity" or "acceleration" can be replaced with "rate of change" or "slope." Other questions that include phrases, such as "change in velocity" or "change in position" can be replaced with "area under a curve." Also, the physics program at EMCC relies heavily on pictures and graphs, so this emphasis was also brought into the new CCI. With Desbien's assistance, seven of the questions were rewritten, reviewed by other faculty members, and used.

In total, the researcher met individually with two chemistry, three physics, and three calculus faculty members from EMCC to develop and/or review new questions for consideration. The researcher also discussed the changes with Bagley who also provided suggestions. Table five summarizes changes made to the Spring 2018 using a more commonsense approach.

Table 4: Summary of Changes made to CCI

TOPIC	CHANGES
Limits	Removed limit notation and utilized a graph with explanation
Derivative	Replaced the word ‘derivative’ with ‘slope’
Integral	Added two graphs, replaced word ‘integral’ with ‘area’ – incorporating opposite areas (positive/negative)
Integral	Added graph, replaced word ‘integral’ with ‘area’ – included a follow up question asking for rational as to why student picked the answer they did – incorporated positive/negative area
Derivative	Added rate of change question of water flowing into cylinders of different radii; students determine which graph represented the volume vs. height graph for the given scenario
Integral	Added change of position scenario incorporating positive/negative change
Reimann Sum – Integral	Added scenario for which students had to interpret the sum of the area of the rectangles under the curve – also included a follow up question which asked students to interpret the actual area under the curve (goal is to see if students thought there was a difference between summing up the rectangles vs. actual)
Infinity	Added question regarding number of numbers between two values
Limit	Question involves long term behavior of a ball drop
Derivative	Replaced ‘derivative’ with slopes – students were given an example of how to draw a “slopes graph” then asked to determine which graph was the slopes graph of a given function – Bagley suggested trying this to see if this helped students at the pretest level have a chance to answer correctly
2^{nd} Derivative	Removed question regarding 2^{nd} derivative and application to position of rocket – with addition of new questions, CCI became long. The question will be added back in, once the follow up questions are removed – this question used 2^{nd} derivative notation, too.

Problems 16-23 still included calculus language. Through multiple interviews and brainstorming sessions, it was difficult to create an entire CCI using commonsense language without the question assessing multiple concepts and becoming too wordy. This will be further discussed in chapter five pertaining to next steps.

Data collected for Fall 2018 was strictly to view the wording of the CCI, determine top distractors, and have the CCI ready for comparison between traditional calculus versus learning community. The posttest was not the same as the pre-test during this semester. Once students provided their rationale on the pre-test and assignments were reviewed, the posttest included two questions with very small modification in wording. Regardless, a comparison of pre- to post-test was not conducted. Student interviews were held on the final version of the CCI to be used for finishing updates to the CCI. Faculty agreed on having two semesters of data to be collected to review the CCI before making in more changes.

Final Version of CCI: Spring and Fall 2019

Research Question One (RQ1).

In the fourth and final draft used for comparison between the traditional calculus classes and learning community classes at EMCC, no changes were made to the CCI. For both semesters, only students who took both the pre- and posttest were used to analyze the data. In total, 195 students were part of this portion of the study, with 59 students being from the learning community. No statistical analysis of this data was done for RQ1.

As referenced in the methodology chapter with determining if a CCI can be created, Adams and Wieman (2010) recommendations were followed. To recap, the authors recommended (1) giving the instrument as a pre-posttest (not one or the other), (2) simplify administering, grading, and utilizing class time, (3) ensuring the instrument provided value to the instructor; and (4) certifying the tool measures what it claims to measure.

Give as Pre-Posttest and No Training Needed

In both spring and fall 2019 semester, faculty were able to give the CCI in fewer than 40 minutes, as a pre- and posttest, with emailed directions to follow (see Appendix F). The researcher received few to no questions regarding how to give the CCI. Faculty were given bubble sheets and the CCI for student use, and faculty returned the bubble sheets to the researcher. The only question regarding the CCI was how to send the bubble sheets back to the researcher, which was simple to address.

Value to Instructor and Claims of Tool Measurement

The grading of both the pre- and posttests was completed with the Gravic scanner, and reports were emailed to each faculty for review. Faculty were able to review the pre-test results by week two of the semester. The posttest results, along with a comparison of pre- to posttest scores, were emailed during finals week to review the data. Faculty were able to review individual student pretest scores and posttest scores.

In fall 2019, EMCC calculus faculty met to discuss calculus in general, including the CCI results of Spring 2019. Data provided surprises and insight to faculty about student thinking. For example, with the changes to the first limit question, which now included a graph, faculty believed the question was too simple. Yet only 20% of students were able to answer this question correctly (for similar sample questions to the CCI, see Appendix G).

Another surprising result for faculty pertained to two Riemann sum questions, which are essentially the same question. The first of these questions asks students to interpret the area of several rectangles under a curve with the follow-up question asking about the actual area. Faculty expected students to select the same answer for both questions, yet 65% of students answered the first one correctly with only 52.13% answering the second question correctly. This information showed faculty the disconnect students have between rectangles and actual area.

Not only were faculty finding the tool informational, but through student interviews, students said each question was measuring what was claimed to be measuring. Students said the questions did not assess multiple concepts. Lastly, the Cronbach alpha score was 0.652 for n = 195 students taking the CCI. While this score does not meet the socially acceptable 0.7 score or above, in a personal conversation with Bagley (July, 2020), it was determined that this could be due to the last eight questions using calculus language. This possibility will be further explored in Chapter Five. Thus, in reviewing the data, a CCI can be written that provides faculty information about student misconceptions.

Research Question Two (RQ2)

Was there a statistically significant difference between mean scores on the CCI among students who were in the calculus/physics learning community as compared to students taking the stand-alone calculus courses?

<u>Analysis and Results</u>

This section is broken into four parts for analysis and review: pretest scores, posttest scores, difference scores, and Hake Gains. Pretest and posttest scores were collected, and the raw difference between the scores along with the Hake gains were calculated using SPSS. A further dive into the learning community data was done by reviewing faculty who had taught less than two years in the learning community as compared to one who had over seven years of teaching in the learning community environment.

A visualization of each data set is presented in Figures 2-8 through the use of histograms. Descriptive statistics and ANOVA for each part is provided which includes a comparison of scores between MAT220 and MAT221. Table 5 provides a reminder of the participants in this study.

Table 5: Participants Spring 2019-Fall 2019 Reminder

ESTRELLA MOUNTAIN COMMUNITY COLLEGE	# OF STUDENTS
MAT220 (Label 0) – Traditional Calculus	n = 136
MAT221 (Label 1 0 Learning Community	n = 59
Total	n = 195

Pre-Test Results and Analysis

This section will be dedicated to the pretest results of the CCI. Figures 2 and 3 provide the visuals for the scores, including a comparison between MAT220 and MAT221, followed by table 6 and 7 with statistical information.

Figure 2: Frequency of all Pretest Scores

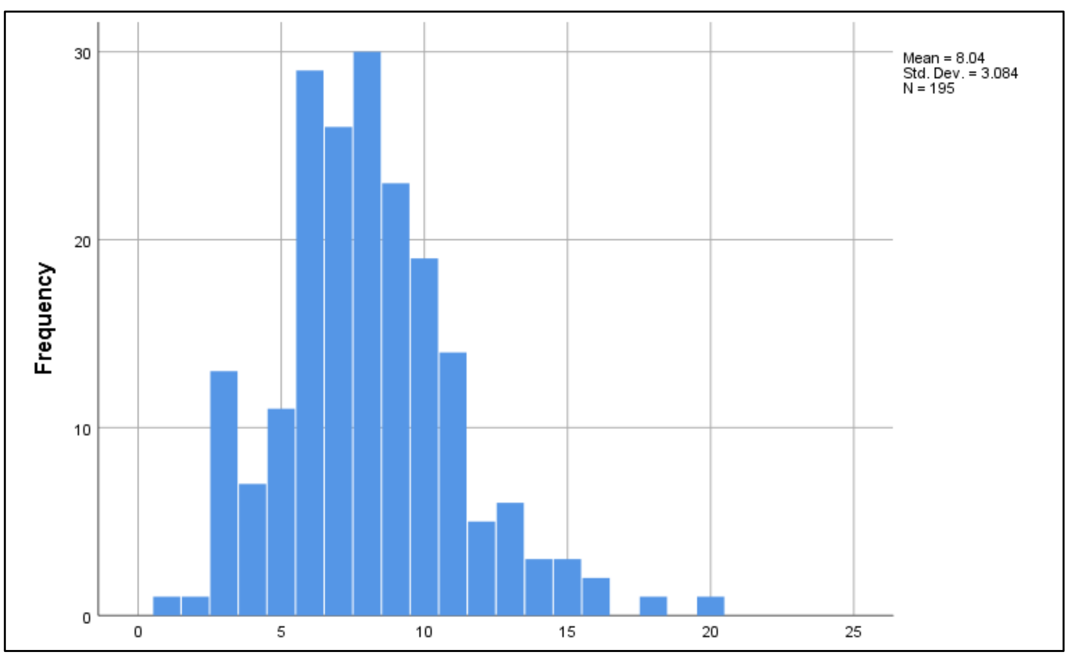


Figure 3: Frequency of Pretest between MAT220 (label 0) and MAT221 (label 1)

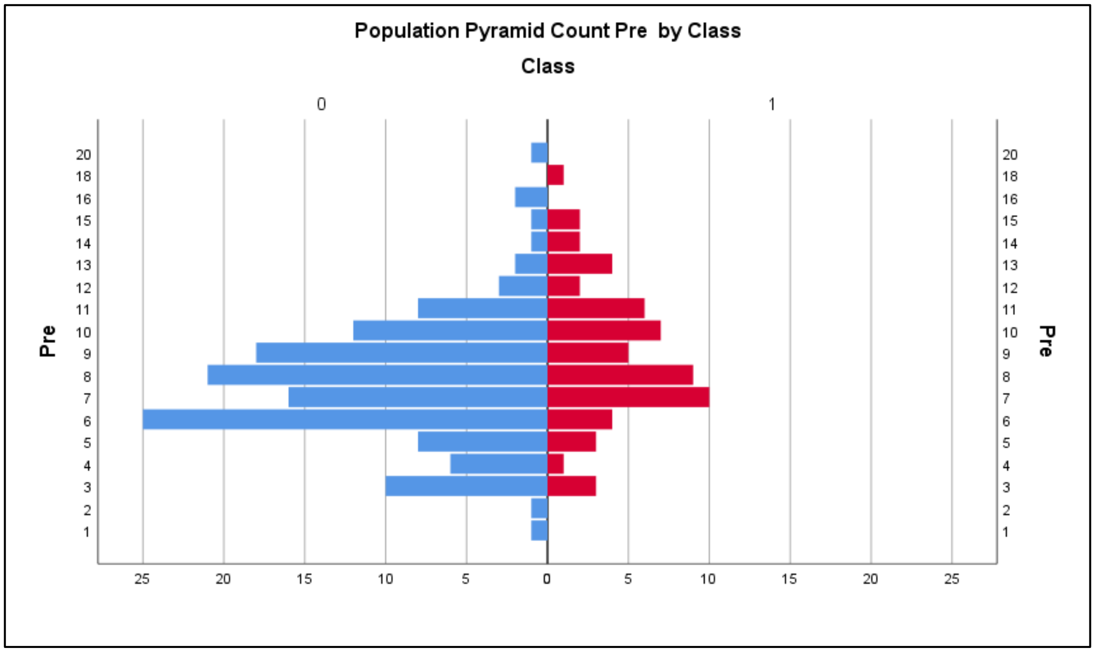


Table 6: Mean and Standard Deviation on Pretest Scores for MAT220 and MAT221

Class	Mean	N	Std. Deviation
MAT220	7.65	136	2.975
MAT221	8.93	59	3.167
Total	8.04	195	3.084

Table 7: Analysis of Variance of Pretest scores for MAT220 vs. MAT221

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	67.961	1	67.961	7.382	.007
Within Groups	1776.788	193	9.206		
Total	1844.749	194			

Table 7 makes it apparent that learning community students begin instruction with higher pretest scores. Thus, there are differences between student populations between MAT221 and MAT220 courses. This may be due to a smaller sample size in the learning community classes or students in MAT221 are typically students in the "hard sciences": engineering, computer science, or physics majors. While traditional calculus courses also include these same majors, MAT220 also includes students in the soft sciences, such as pre-med and psychology. In order to answer RQ2 with different populations taking the CCI, the difference between pre- and post-scores, as well as the Hake Gain, were used and will be reviewed later in this chapter.

The final pretest analysis includes the review of experience within the learning community faculty. Table 8 shows students within MAT221 are similar with no difference in pretest scores.

Table 8: Analysis of Variance of Pretest Scores between Newer and Experienced Faculty

	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG.
Between Groups	18.222	1	18.222	1.843	.180
Within Groups	563.506	57	9.886		
Total	581.729	58			

Post-Test Results and Analysis

This section will be is a review of posttest results of the CCI. Figures 4 and 5 provide the visuals for the scores, including a comparison between MAT220 and MAT221, followed by Table 9 and 10 with statistical information.

Figure 4: Frequency of all Posttest Scores

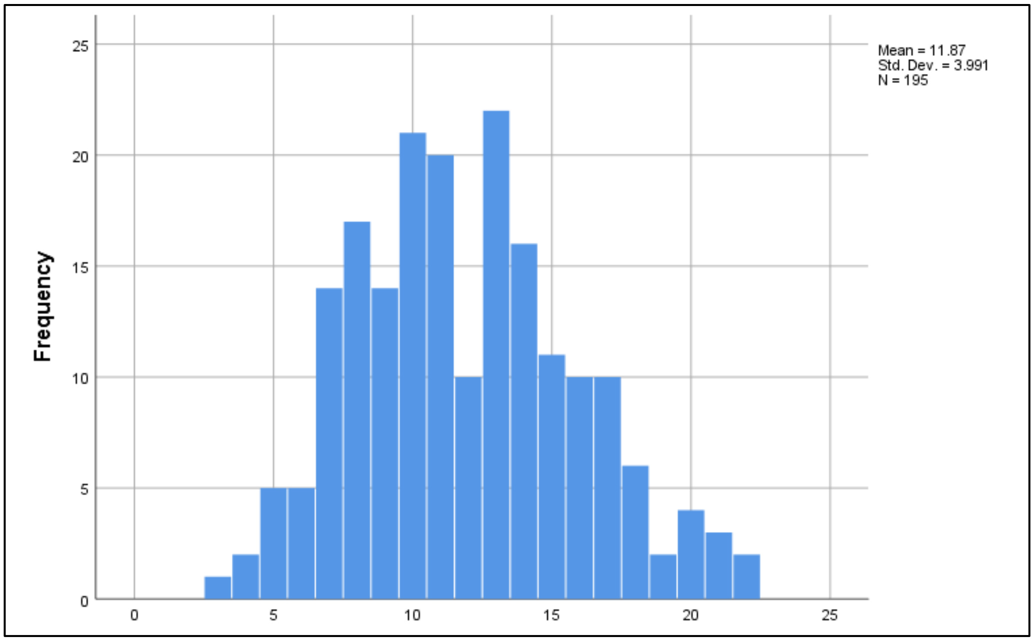


Figure 5: Frequency of Posttest score for MAT220 (Class 0) vs. MAT221 (class 1)

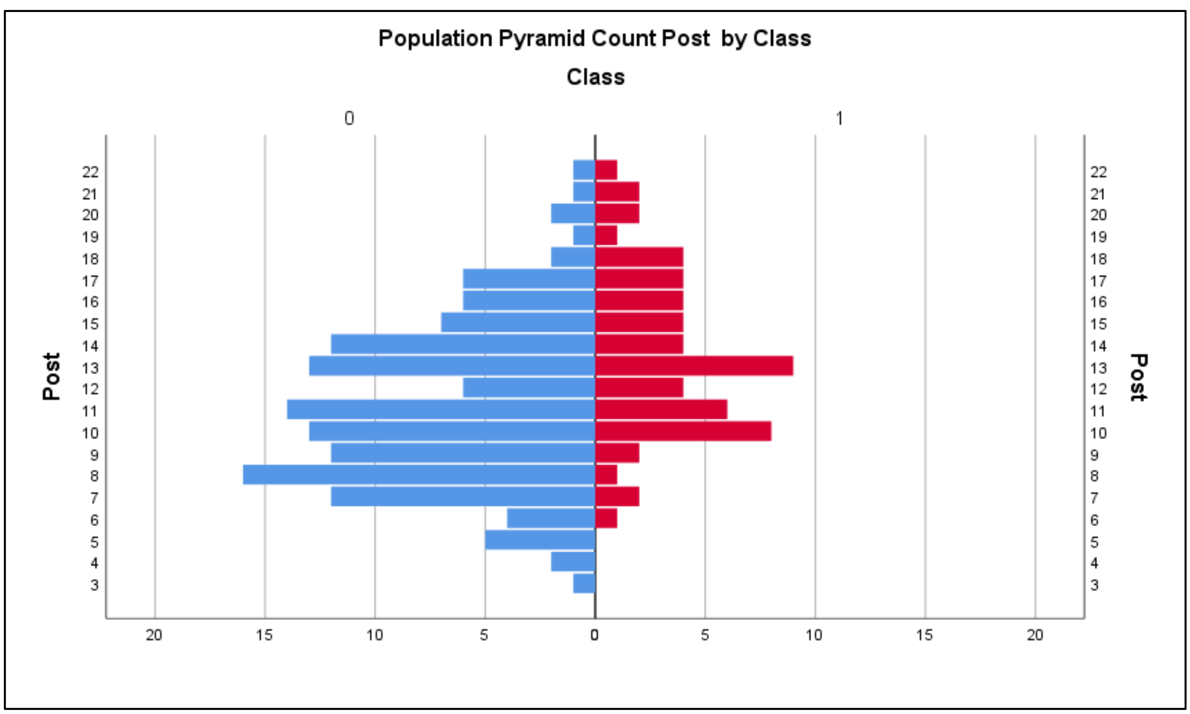


Table 9: Mean and Standard Deviation on Posttest Scores for MAT220 and MAT221

Class	Mean	N	Std. Deviation
MAT220	11.13	136	3.874
MAT221	13.56	59	3.766
Total	11.87	195	3.991

Table 10: Analysis of Variance of Posttest scores for MAT220 vs. MAT221

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	242.373	1	242.373	16.424	.000
Within Groups	2848.160	193	14.757		
Total	3090.533	194			

While students in the MAT221 clearly outperformed MAT220 students on the posttest, this is to be expected since the MAT221 students started off with higher pretest scores.

In reviewing the MAT221 less experienced learning community faculty as compared to the more practiced faculty member, Table 11 shows there was a statistically significant difference between the MAT221 courses.

Table 11: Analysis of Variance of Posttest Scores between Newer and Experienced Faculty

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	106.006	1	106.006	8.269	.006
Within Groups	730.706	57	12.819		
Total	836.712	58			

Raw Difference Results and Analysis

This section provides a summary of the difference between the pre- and posttest scores. Figures 6 and 7 are the histograms for all data including a comparison of MAT220 to MAT221. Tables 13 and 14 include the descriptive and comparison data. Please note that a negative difference means the students scored higher on the pretest than their posttest, and therefore had a loss. A zero value represents the same score on the pre and posttest, and a positive difference means the posttest was a higher score.

Figure 6: Frequency of Raw Difference

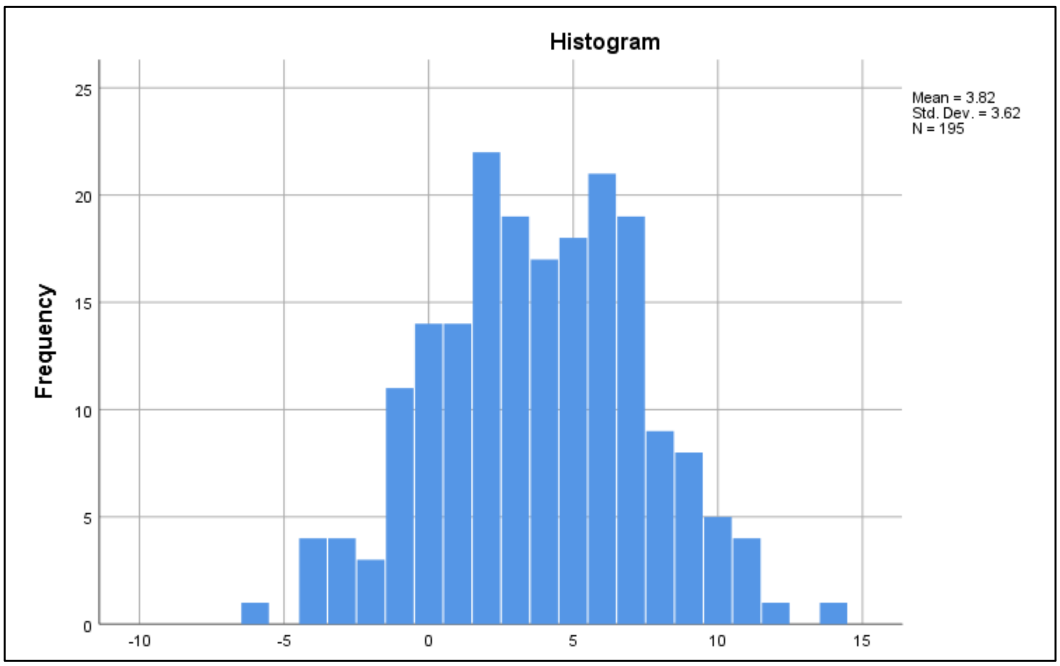


Figure 7: Frequency of Raw Differences for MAT220 (Class 0) vs. MAT221 (class 1)

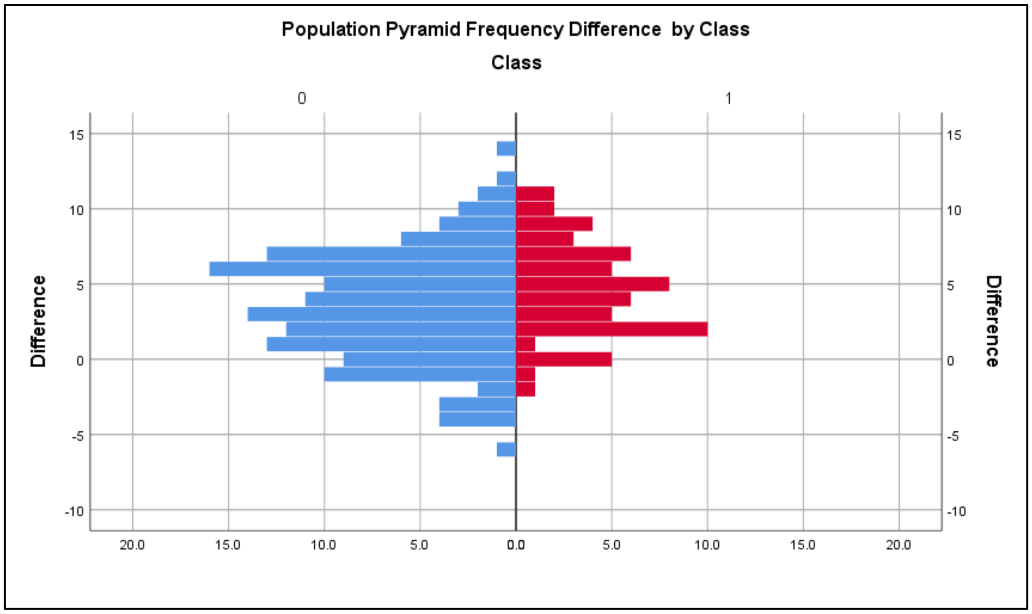


Table 12: Mean and Standard Deviation on Raw Difference Scores for MAT220 and MAT221

Class	Mean	N	Std. Deviation
MAT220	3.49	136	3.769
MAT221	4.59	59	3.147
Total	3.82	195	3.620

Table 13: Analysis of Variance of Raw Difference scores for MAT220 vs. MAT221

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	50.510	1	50.510	3.912	.049
Within Groups	2492.208	193	12.913		
Total	2542.718	194			

Table 12 shows an average gain of 3.49 points from pre to post in MAT220 with the learning community class having an average gain of 4.59 points. There is a statistically significant difference between courses and the raw difference in their scores with $\alpha = 0.049$.

In comparing newer faculty within the learning community courses to the one with more experience, there was also a statistical significance between the two groups. The more practiced faculty member showed higher gains from pre to posttest.

Table 14: Analysis of Variance of Difference Scores between Newer and Experienced Faculty

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	61.831	1	61.831	6.878	.011
Within Groups	512.406	57	8.990		
Total	574.237	58			

Hake Gain Results and Analysis

This final section will calculate the Hake gain of each student. Figures 8 and 9 provide the visuals for the scores, including a comparison between MAT220 and MAT221, followed by Tables 15 and 16, which include descriptive and comparison data.

Figure 8: Frequency of Hake Gain for all Courses

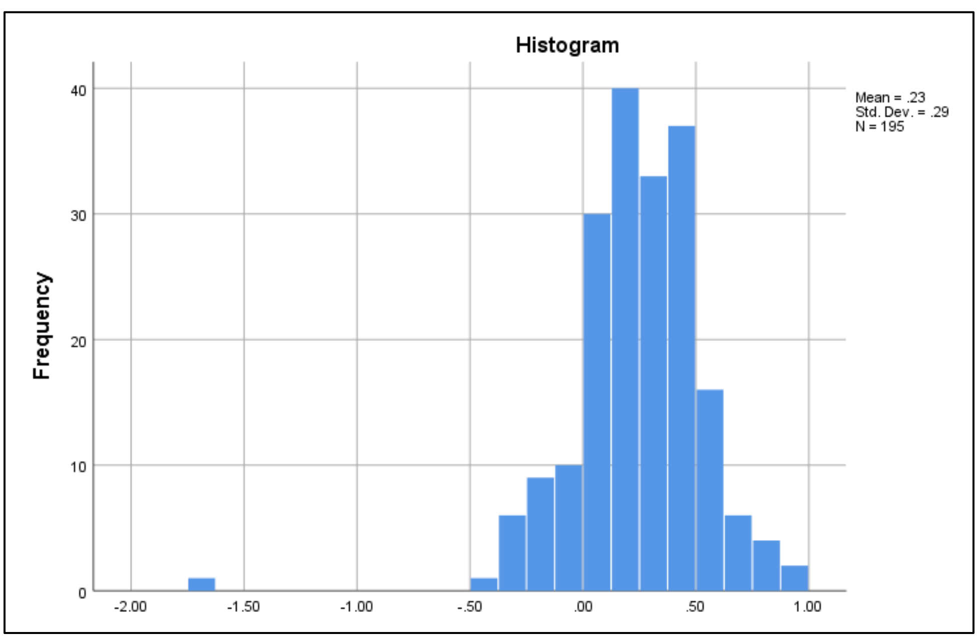


Figure 9: Frequency of Hake Gain for MAT220 (Class 0) vs. MAT221 (class 1)

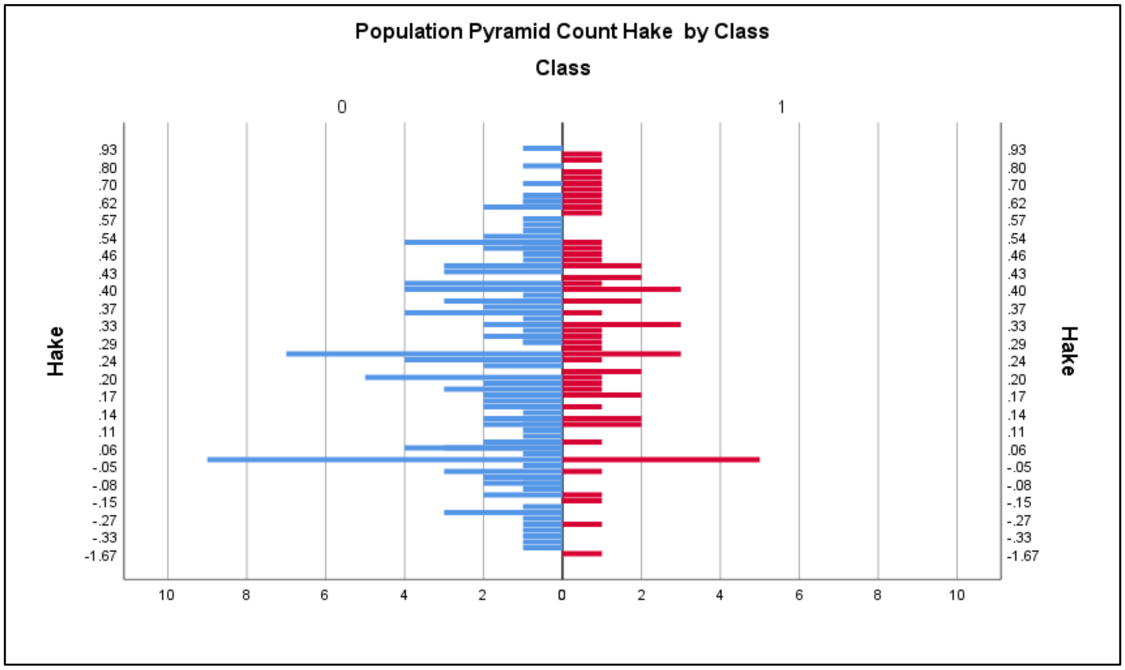


Table 15: Mean and Standard Deviation for Hake Gain for MAT221 and MAT220

Class	Mean	N	Std. Deviation
MAT220	.2143	136	.25366
MAT221	.2772	59	.35914
Total	.2333	195	.29013

Table 16: Analysis of Variance for Hake Gain for MAT220 vs. MAT221

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.163	1	.163	1.944	.165
Within Groups	16.167	193	.084		
Total	16.330	194			

As illustrated in Table 16, with $\alpha = 0.165 > 0.05$, there is not a statistical significance in the Hake gain scores between MAT220 and MAT221. As a reminder the hypothesis for RQ2 and alternative hypothesis are as follows:

Hypothesis for RQ2

> H0: For students who completed first semester calculus/physics learning communities, there was no significant difference in the mean scores on the CCI versus students who completed first semester stand-alone calculus courses.

Alternative Hypothesis for RQ2

> H1: For students who completed first semester calculus/physics learning communities, there was a significant difference in the mean scores on the CCI versus students who completed first semester stand-alone calculus courses.

While there was a statistically significant difference in the raw difference scores, there was not one with the Hake gain scores. Thus, the null hypothesis will be retained.

In an effort to better understand this data, Table 17 shows a comparison between the less experienced faculty in the learning community as compared to the one with more practice had an alpha score of 0.007. See table 18.

Table 17: Analysis of Variance of Hake Gain between Newer and Experienced Faculty

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.898	1	.898	7.775	.007
Within Groups	6.583	57	.115		
Total	7.481	58			

With having three of the four MAT221 courses taught by newer faculty to the learning community environment, this may be why the Hake gain scores were not statistically significant. This, in turn, may be a reason for retaining the null hypothesis.

Faculty new to the learning community not only were learning how to co-teach with physics faculty, but they were also learning how to contextualize calculus with the physics and how to incorporate ambitious teaching pedagogies all in one. The three physics faculty members with over six years of teaching experience in the learning community had a major advantage.

CONCLUSION

Research question one, can a CCI be developed, was addressed through interviews, collaborative efforts with faculty across three different colleges, and student work. Clearly, a CCI can be developed. In regard to RQ2, while the students in MAT221 consistently outperformed MAT220 students on posttest and raw difference scores, the pretest scores showed that the two student populations are different prior to instruction. With Hake gain scores not being statistically significant, the null hypothesis is retained. This could be due to having three of the four learning community math faculty newer to this student-centered contextualized teaching environment.

CHAPTER FIVE: SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH

INTRODUCTION

This chapter will summarize limits of the study, lessons learned, implications for research, and future recommendations to further the research.

LIMITS ON RESEARCH STUDY

This research study has several limitations. First, learning outcomes for calculus at EMCC have been defined, but these learning outcomes are not aligned nationwide nor within the Maricopa district. Thus, while the CCI may meet the needs of EMCC faculty, the model may not apply nationally.

Second, the CCI, like Epstein's CCI, still includes calculus language for the last eight problems. Therefore, estimating conceptual understanding and student gains may be underestimated.

Third, all the students who were used in comparison on the CCI were enrolled at EMCC. While two other colleges participated in developing the tool, their students were not part of the final data analysis. Two of the physics faculty members at EMCC utilize a pedagogy called discourse management, which has shown to improve student understanding (Desbien, 2002). This pedagogical technique is not widely used across the nation; thus, the approach may affect the study's results, and the results may not generalize to the broader calculus population including calculus/physics learning communities at other colleges.

Next, only 59 students involved in this study were from the calculus/physics learning community and may be considered a small sample. In addition, three of the four learning community math faculty were new to this teaching environment. Only students who completed the course were included, so the results may have been different had the other students who withdrew remained.

Another limitation is that EMCC is a Hispanic Serving Institution (HSI) located in southwestern United States. Because of this geographic location and study population, the results of the study may not generalize to the rest of the U.S. population or other areas of the world. And lastly, the creation of a concept inventory takes several years to create. While this research occurred for a little over four semesters, more work needs to be done to improve the CCI.

LESSONS LEARNED

Writing a CCI has proven to be difficult, time consuming, and eye opening regarding the vast differences between calculus instructors and their methods of instruction. First, writing 20+ questions using commonsense language without calculus verbiage proved to be challenging. Researching questions used by other colleges, interviewing faculty, and reviewing other calculus concept inventories is not enough. This researcher acknowledges that reaching out to people, like Bagley, should have occurred much sooner in the research cycle. Bringing in other calculus faculty across the nation who have similar goals with creating a CCI should also have been done early in the process, in the first semester.

As reflected in this quotation by Bagley et al. (2016), calculus education is important to a wide range of curricula and student learning outcomes:

> With the centrality of calculus to undergraduate mathematics programs and a variety of mathematically intensive partner disciplines, such as economics, physics, and engineering, there is a need to look at the course's learning outcomes. Recent efforts through the MAA's National Studies of College Calculus have helped the mathematical community better understand the current state of calculus programs around the country. Data and research on student outcomes in calculus, especially with regards to conceptual knowledge, lag somewhat behind. Part of this is attributable to a lack of appropriate, well-validated instruments to measure outcomes. As most faculty are not trained in rigorous assessment development, they often depend on others for instruments to measure student learning in courses and programs.

Given the shortcomings of the (Epstein's) CCI, as well as the inherent limitations of a static instrument with set questions, we argue that there is a need to create an item bank, consisting of rigorously developed and validated questions, on which we have solid psychometric properties, that measure students' conceptual understanding of differential calculus. Such an item bank would significantly impact teaching and learning during the first two years for undergraduate STEM. Such an item bank could be used by instructors for formative and summative assessment during their calculus courses to improve student learning. The resources could also be used by researchers and evaluators to measure growth of student conceptual understanding during a first semester calculus course to compare gains of students in classrooms implementing differing instructional techniques.

Understanding and realizing that one size does not fit all was another revelation; colleges across the nation may have different student populations with varying needs. The researcher has been teaching at EMCC for almost eighteen years and is familiar with EMCC's first semester calculus students. Also, EMCC calculus faculty work closely with physics faculty, and the curriculum has been developed to align calculus and physics, and this is not common at other colleges. Other higher education institutions may have students pursuing predominately psychology or economic degrees, and calculus faculty may not have working relationships with other STEM faculty. Thus, developing a question item bank, as suggested by Bagley et. al (2016), may meet the needs of these faculty, as well as those who may have different student populations, for example in pre-dominantly rural settings or multi-cultural urban areas.

One of the most significant personal lessons learned by this researcher was gained through interviews with two particular students. These students schooled the researcher about how a different native language affected their interpretation of test questions. These two students spoke Spanish as their native language and spoke English as a second language. When completing tests, they typically translated as they read into Spanish before answering the question. During the interview, the students explained how one question read differently when translated into Spanish, and this influenced them to select the wrong answer. Through the interview process, they both helped the researcher modify one of the questions so that the English statement translated into Spanish had the same meaning.

The importance of understanding language use, listening to students, and ensuring assessment questions are understandable are critical to faculty correctly using assessment results to improve teaching and learning. With EMCC being a Hispanic Serving Institution, EMCC faculty may need to be more aware of language barriers students may have when translating and understanding test questions.

Another realization gained during this study, even with the literature read prior to the study, was the researcher’s first-hand experiences with learners’ struggle with question wording, mathematical definitions, and the symbology of mathematics. This struggle makes writing questions difficult because it became clear that students may answer a question incorrectly, not because they do not conceptually understand a question, but because they had gotten lost in the language of the question, definitions, or symbols. Thus, this awareness made the faculty members' task in deciphering why students miss a particular problem more difficult.

IMPLICATIONS FOR RESEARCH

Continuation of the learning community and bringing in different calculus faculty to teach in this environment will continue. Teaching MAT221 is, not only a way for calculus faculty to collaborate with physics colleagues, but provides a professional growth opportunity for both faculty members to learn from each other. While faculty have been expected to teach in the learning community for at least a year, the data suggests having faculty teach for at least four semesters to become more practiced in the learning community environment.

The continual alignment of curriculum between calculus and physics will continue, and this will begin to bleed into courses taught by part-time faculty. Discussions, including workshops, between full- and part-time faculty will occur to provide professional development for those who are unable to teach with physics faculty.

EMCC physics and calculus faculty are looking to present their partnership with each other at national conferences such as American Association of Physics Teachers and Mathematical Association of America. Contextualizing mathematics through labs done in the learning community have been brought into second semester calculus and differential equations. More contextualized learning for STEM courses besides physics need to be developed as well.

Through the recent results of the CCI and common final question exam (as mentioned in Chapter 1), this researcher wants to identify grant opportunities that support teaching and learning training opportunities to bring in faculty from high schools and other colleges. In a similar grant for physics instructors, Desbien (personal conversation, 2018) was a co-principal investigator and oversaw training of physics teachers in incorporating and modeling discourse management. This researcher is hoping to identify grant support that will support similar efforts for calculus faculty.

Another next step for this research is for the researcher to share the findings with Bagley and potentially develop a national CCI. The researcher plans to attend national math conferences to share the CCI results and further the creation of this type of assessment tool in calculus.

And finally, conversations with EMCC mathematics faculty about the results of the first 15 questions will be continue. As previously mentioned, the first fifteen questions were written at a commonsense level, thus are questions that could be asked in an intermediate or college algebra setting. The findings of student misconceptions about slope, rate of change, area, and interpreting graphs could be addressed in the courses prior to calculus to possibly help address misconceptions prior to coming to calculus.

FUTURE RESEARCH

The CCI needs to continue being analyzed using point biserial analysis, modified and adapted using data, and include other concepts such as differentials. The follow-up questions currently in the tool will eventually be removed once faculty believe they have enough information to make conclusions about student answers. This researcher also plans to add more questions that use commonsense language and remove some of the questions that include calculus language and notation. By collaborating with faculty across the nation, a question bank should be created. As Bagley et al. (2016) suggest, validated questions need to be developed.

Activities in the learning community need to be pinpointed to determine what practices address misconceptions, and what practices and approaches can be applied into traditional calculus classes. In addition, more calculus faculty need to teach in the learning community to raise their teaching skill set by incorporating active learning strategies.

FINAL CONCLUSIONS

The intent of this research was to show how a calculus concept inventory can be created and that students who go through the calculus-physics learning community will have higher learning gains using a CCI. While a solid, usable concept inventory has been created, this researcher plans to continue further develop the tool for broader use. With the data analysis not showing statistically significant gains between MAT220 and MAT221, the researcher will look further into this data when calculus faculty have more experience teaching in the environment. The effects of a CCI on student's conceptual understanding is clearly evident to this researcher when she teaches MAT220 and MAT221. The initial development and use of the CCI is complete. However, the formative evaluation and effectiveness of the learning community addressing misconceptions continues.

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APPENDIX A: PRIOR ASSESSMENTS COMPARING TRADITIONAL CALCULUS TO LEARNING COMMUNITY

Estrella Mountain Community College has a website called Comprehensive Assessment Tracking System (CATS) for faculty to document assessments. This website can be found at https://cats.estrellamountain.edu. Here are two sample assessments performed with comparing the learning community to the traditional calculus courses.

Common Final Assessment

Monday, January 9, 2017 to Friday, December 15, 2017

What is the Need/Assessment?:
1. Ensure calculus faculty are covering core concepts. 2. Use results to compare calculus/physics learning community to stand alone calculus courses.

Describe the necessity for this change:
1. Faculty are covering several competencies, so this will make sure the most important ones are emphasized. 2. Show contextualized learning improves student scores.

Describe what will be (or was) implemented to affect change:
1. Faculty are informed of the common questions at the beginning of the semester. 2. From previous CATS submitted about the success of the learning community, calculus and phyics faculty have officially added more learning communities to the schedule. Starting Fall 17 and each semester on, two 1st semester learning communities are offered and one 2nd semester learning community.

Interpret, compare and describe the results of the change:
1. Both full time and part time faculty emphasize the concepts from the common questions. 2. The calculus/physics learning community students continually outperform the stand alone calculus courses (see attached Spring 17 and Fall 17 results as well as previously written CATS). Also, from a previous CATS, we see higher success in calculus 3 when students come from the learning community.

After analyzing the information, what are the next steps?:
1. Continue to support the learning communities. 2. Becky hopes to offer professional development workshops with calculus faculty who teach stand alone calculus courses. These workshops will work with faculty on how to incorporate labs into the calculus classroom, as well as use Vernier Probe Ware with students. 3. Organize meetings prior to start of semester with calculus faculty to review common final results.

Abstract:
Not all faculty have the time or nor want to teach in the calculus/physics learning community. So, how do we help faculty who teach stand alone calculus courses? Also, stand alone calculus courses do not have another instructor present to help emphasize concepts. So, Becky is teaching a stand alone calculus course in Fall 18 to see if she can cut down on some competencies, incorporate labs, and she will compare her course to other instructors who teach non-learning community calculus courses. Did Becky's class perform the same, worse or better on the common final? If worse, why? If the same, why?

Division/Department: Mathematics

APPENDIX B: SIX YEARS OF DATA

The following was taken from the Comprehensive Assessment Tracking System. This is six years of data review looking at first semester learning community student performance in calculus II and III, and physics II and III.

Monday, August 2, 2010 to Friday, May 13, 2016

Abstract:
Learning Community (LC) faculty have been saying for 6 years that the main focus on the LC is to help students in future STEM courses. Majoring in a STEM field is difficult; math is a barrier for most students. Approximately 20% of community college students start as a STEM major with 69% of them changing it to non-STEM. The LC course is designed to help students be successful STEM students and truly understand how math and physics are intertwined. So, student grades were analyzed from fall 2010 - spring 2016. Students that went through the LC vs. those that did not did very well in university physics II and III (95% and 100% passing rates for both groups, respectively). For calculus III, 81.5% non LC students passed the course the first time while 95.3% of the LC students passed. A chi-square test of independence was used to test the relation between completing the LC and passing MAT241 at EMCC. We found that there is a significant relationship X^2 (1, N=215) = 7.42, p<.01. Those students who completed the LC were significantly more likely to pass MAT241 than students who did not take the LC. See attached for more detail.
Division/Department: Mathematics

Table 18: Data from Fall 2010 – Spring 2016

	PHY131	PHY241	MAT241
Total # Students to take course	183	21	246
Total # Non LC students	110	8	179
Total # NON LC students to pass	105	8	146
Percent to pass:	95.40%	100%	81.50%
Total # LC students to take	73	13	65
Total # LC students to pass	70	13	62

Info regarding data:

- Did not count students who repeated courses – only counted whether they passed 1st time or not – also, 4 students chose to retake the LC, these students were only counted once
- Did not include students who dropped the course in the 1st week of the semester
- A total of 156 students have gone through the LC since fall 2010 with 100 passing the LC. Of the 56 students who failed one or both classes in the LC, several took the "traditional" path and were very successful in the follow up courses.

APPENDIX C: MARICOPA COURSE COMPETENCIES

The following competencies can be found at https://curriculum.maricopa.edu

Calculus with Analytic Geometry I

Course: **MAT220**	Lecture **5.0** Credit(s) **5.0** Period(s) **5.0** Load
	Course Type: **Academic**
First Term: **2020 Summer**	Load Formula: **S**
Final Term: **Current**	

Description: Limits, continuity, differential and integral calculus of functions of one variable.

Requisites: Prerequisites: A grade of C or better in (MAT182 and MAT15+), or MAT187, or an appropriate District placement.

Course Notes: Students may receive credit for only one of the following: MAT220 or MAT221.

Course Attributes:
General Education Designation: Mathematics - [MA]
Arizona Shared Unique Number SUN#: MAT 2220

MCCCD Official Course Competencies

1. Analyze the behavior and continuity of functions using limits. (I)
2. State the definition and explain the significance of the derivative. (II)
3. Compute the derivative using the definition and associated formulas for differentiation. (II)
4. Solve application problems using differentiation. (II)
5. State and explain the significance of the Fundamental Theorem of Calculus. (III)
6. Compute anti-derivatives, indefinite and definite integrals of elementary functions. (III)
7. Read and interpret quantitative information when presented numerically, analytically or graphically. (I, II, III)
8. Compare alternate solution strategies, including technology. (I, II, III)
9. Justify and interpret solutions to application problems. (I, II, III)
10. Communicate process and results in written and verbal formats. (I, II, III)

MCCCD Official Course Outline

I. Limits and Continuity
  A. Definitions
  B. Computations with limits
    1. Algebraic
    2. Numerical
    3. Graphical
  C. Infinite limits
  D. Limits at infinity
II. The Derivative
  A. Definition
  B. Techniques of differentiation
  C. Extrema of a function
  D. First and second derivative test
  E. Applications of the derivative
III. The Integral
  A. Anti-derivatives and the indefinite integral
  B. Evaluate the definite integral
  C. Properties of the definite integral
  D. Fundamental theorem of calculus
  E. Elementary applications of the integral

Calculus with Analytic Geometry I

Course: **MAT221**	Lecture **4.0** Credit(s) **4.0** Period(s) **4.0** Load
	Course Type: **Academic**
First Term: **2020 Summer**	Load Formula: **S**
Final Term: **Current**	

Description: Limits, continuity, differential and integral calculus of functions of one variable.

Requisites: Prerequisites: A grade of C or better in (MAT182 and MAT15+), or MAT187, or an appropriate District placement.

Course Notes: Students may receive credit for only one of the following: MAT220 or MAT221.

Course Attributes:
General Education Designation: Mathematics - [MA]

MCCCD Official Course Competencies

1. Analyze the behavior and continuity of functions using limits. (I)
2. State the definition and explain the significance of the derivative. (II)
3. Compute the derivative using the definition and associated formulas for differentiation. (II)
4. Solve application problems using differentiation. (II)
5. State and explain the significance of the Fundamental Theorem of Calculus. (III)
6. Compute anti-derivatives, indefinite and definite integrals of elementary functions. (III)
7. Read and interpret quantitative information when presented numerically, analytically or graphically. (I, II, III)
8. Compare alternate solution strategies, including technology. (I, II, III)
9. Justify and interpret solutions to application problems. (I, II, III)
10. Communicate process and results in written and verbal formats. (I, II, III)

MCCCD Official Course Outline

I. Limits and Continuity
  A. Definitions
  B. Computations with limits
    1. Algebraic
    2. Numerical
    3. Graphical
  C. Infinite limits
  D. Limits at infinity
II. The Derivative
  A. Definition
  B. Techniques of differentiation
  C. Extrema of a function
  D. First and second derivative test
  E. Applications of the derivative
III. The Integral
  A. Anti-derivatives and the indefinite integral
  B. Evaluate the definite integral
  C. Properties of the definite integral
  D. Fundamental theorem of calculus
  E. Elementary applications of the integral

Brief Calculus

Course: **MAT213** First Term: **2020 Summer** Final Term: **Current**	Lecture **4.0** Credit(s) **4.0** Period(s) **4.0** Load Course Type: **Academic** Load Formula: **S**

Description: Introduction to the theory, techniques, and applications of the differential and integral calculus of functions with prob

Requisites: Prerequisites: A grade of C or better in MAT15+, or MAT187, or an appropriate District placement.

Course Notes: Students may receive credit for only one of the following: MAT212 or MAT213.

Course Attributes:
General Education Designation: Mathematics - [MA]
Arizona Shared Unique Number SUN# 2212

MCCCD Official Course Competencies

1. Find derivatives of functions using both the definition and theorems. (I)
2. Use the derivative to solve and analyze application problems related to business, life, and the social sciences. (II)
3. Use technology to model, solve, and analyze problems related to real-world applications. (II, IV)
4. Find the integral of functions using theorems. (III)
5. Use the integral to solve and analyze application problems related to business, life, and the social sciences. (IV)

MCCCD Official Course Outline

I. Derivatives
  A. Limits
  B. Slope and rate of change
  C. Definition of the derivative
  D. Rules of differentiation
    1. Product
    2. Quotient
    3. Chain rules
    4. Implicit
    5. Related rates
    6. Higher order
II. Applications of the Derivative
  A. Increasing and decreasing functions
  B. Extrema and first-derivative test
  C. Concavity and second-derivative test
  D. Optimization problems
  E. Applications to business, life, and social sciences, including velocity and marginals
III. Integration
  A. Antiderivatives and indefinite integrals, including substitution and integration by parts
  B. Definite integrals and the fundamental theorem of calculus
  C. Improper integrals
IV. Applications of Integration
  A. Area under a curve
  B. Area between two curves
  C. Applications to business, life, and the social sciences

APPENDIX D: RECRUITMENT EMAILS

Email sent by division chair to faculty across the district.

My colleague, Becky Baranowski, is working on a Calculus **Concept** Inventory Pre-Post test and needs assistance from fellow faculty members that teach calculus in the district. A draft is being piloted this Fall 2017 at EMCC.

Purpose of test:

- Provide feedback to instructors (not students).
- What are the common misconceptions that students have (pre)?
- What concepts are students "all over the place" (pre)?
- (Post) Did your instruction move students to believe a certain way (majority of students answered "b" for a specific problem)? If it is right or wrong, this tells you some info about how you taught.
- Instructor can adjust activities for next semester based off of the pre-post test results.
- Exam is NOT shared with students.

Becky is looking for faculty to:

1. Review questions.
2. Review multiple choice options.
3. Provide feedback (remove questions, add questions, modify current questions, modify multiple choice options).

She is willing to drive to each campus to meet with interested faculty.

IF faculty are interested in also giving this pre-post test, that would be even better. BUT, FOR NOW, she is looking for other interested faculty to help with the creation of a quality pre-post test. If you are already using a test like this, would you be willing to discuss it with Becky?

If you are interested or know any other faculty that would be, please email her at rebecca.baranowski@estrellamountain.edu

Thank you for your time and consideration,

Becky Baranowski
Math Faculty
EMCC

Andrew Norman Burch
Division Chair
Math, Physics, and Engineering Division
Estrella Mountain Community College

The following email was sent by the researcher to faculty.

Dear calculus faculty,

My name is Becky Baranowski, and I am in the process of creating a commonsense calculus misconception pre-posttest (called Calculus Concept Inventory) for 1^{st} semester calculus. Many of us have been using Epstein's CCI, and we are finding that it does not fit our needs. I am looking for faculty who are willing to meet with me to discuss the creation of a new exam. We will review Epstein's CCI, and what works from this tool and what does not. We will discuss misconceptions students have, based off of our teaching experiences. And finally, we will review sample questions already created and need feedback. Any additional suggested questions to add to the CCI are welcome. Please let me know if you are willing to meet and discuss this further.

Thank you for your time and consideration.

The following email was sent to students by the researcher.

Dear calculus students,

My name is Becky Baranowski, and I am looking for students currently in calculus I and those who have already taken calculus I to participate in an interview. Calculus faculty at EMCC are creating a pre-posttest to help us determine how our teaching impacts student's understanding of calculus concepts. The purpose of the pre-posttest is to aid calculus faculty in becoming better instructors. The interview will include you taking the designed test, you provide your rationale as to why you answered the question the way you did, and an opportunity for you to give feedback on how the question is worded. Were you able to understand the question asked? Was the question confusing or what the concept confusing?

This interview is voluntary, will not impact your grade or success in any class, and is an opportunity for you to help us improve our teaching. Please talk to your calculus instructor if you have further questions. You may also contact Becky at rebecca.baranowski@estrellamountain.edu if you would like to ask her any additional questions.

All interviews will last approximately 1 hour.

Thank you for your time and consideration.

APPENDIX E: THEME-RELATED COMPONENTS OF FACULTY INTERVIEWS

Table 19: Theme-Related Components – Quantitative Results

QUESTION	FACULTY INTERVIEW: THEME RELATED COMPONENTS	FACULTY INTERVIEW: QUANTITATIVE RESULTS
4, 14, 17, and 20	Questions written at a college algebra level Questions did not contribute to determining student conceptual knowledge of calculus	All faculty were in agreement to remove these questions from first draft.
8, 12, 18	Faculty spent more time deciphering what the questions were asking Physics faculty answered questions differently than calculus faculty Faculty discussed two possible options for answers	All faculty were in agreement to remove these questions.
5, 10, 13, 22, 9	EMCC: Questions were good, but did not meet the goals of the EMCC CCI faculty wanted to create – faculty drafted different questions SMCC and GWCC: Good questions, but not set on keeping or eliminating – faculty drafted new questions	Nine of the fifteen (60%) faculty agreed to remove questions. Once new questions were drafted and reviewed, all faculty agreed to remove these questions.
1-3, 11, 15, 16, 19, 21	Good questions Assessed conceptual understanding of students Questions provide relevant information to faculty member about what students learned Distractors were good	All faculty were in agreement to use these questions. Each question was slightly modified to not be exactly from Epstein's CCI.

APPENDIX F: EMAIL SENT TO FACULTY ADMINISTERING CCI

All,

I am working on the pre-post conceptual calculus inventory (CCI) and will get copies to you soon. (*Faculty members names)* - I will put these in your mailboxes with answer sheets for students to fill out.

(Faculty members names) - I will put these in the back of your classroom with answer sheets for students.

EVERYONE:

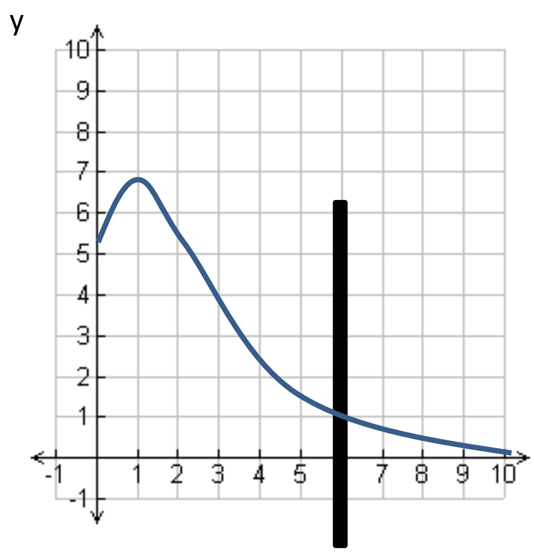
- CCI should take 25-35 minutes
- Have students bubble their answers on the answer sheet provided
- Please do not have them write on the CCI
- Tell students that this CCI does NOT impact their grades. The purpose is to see how our teaching impacted their thoughts about certain math concepts. We are using the information to make changes to our teaching to help students understand the concepts better. Encourage them to try their best.
- If and ONLY if you have class time (this will take an additional 10-20 minutes), please have students answer WHY they chose the answer they did. Have them answer this ***on a separate sheet of paper***. This will allow me to determine why students pick certain answers so that we, as a group, can understand what students are thinking.
- Please give this the first and last week of classes, before finals.
- Return your answer sheets and pre-posttests to me (*Faculty names*- you can leave the CCI in the classroom in the cabinet).

Becky

APPENDIX G: SAMPLE QUESTIONS ON CCI

The following four problems represent a sample of similar problems from the CCI that address conceptual questions.

1. In the graph below, the graph is covered up at <u>exactly</u> x = 6 by the rectangle. As x approaches 6 from both sides, the y-value approaches 1. Which of the following **<u>must</u>** be true about the y-value when x is <u>exactly</u> 6?

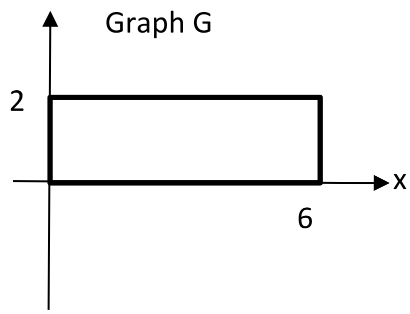


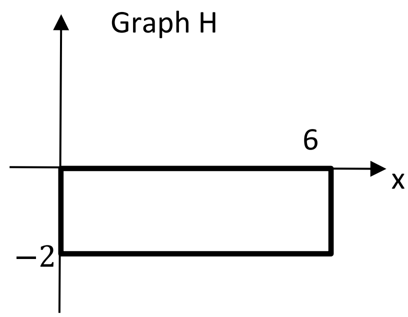
a. The y-value is 1
b. The y-value does not exist
c. The y-value is another number
d. Not enough information has been provided.
e. None of these

2. How many numbers are between 1.0 and 1.9?
a. 0
b. 1
c. Infinite
d. A lot, but not an infinite
e. 0.9
f. I don't know

3. Review the following graphs. In comparing the areas for both *G* and *H*, which of the following represents the comparison?

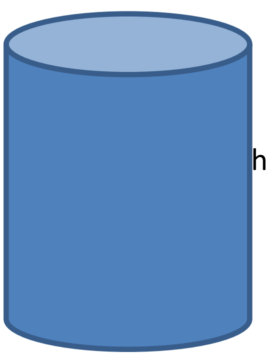
y y



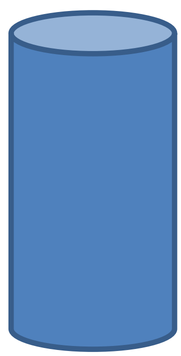


a. Areas are opposite
b. Areas are the same
c. Areas are different, but not opposite
d. Either a or b
e. None of these

4. Below are two different cylinders. Suppose water is flowing in at the same constant rate (gallons per second) into each of these cylinders starting at t = 0 seconds. Which of the following *volume vs. height* graphs would represent this situation?

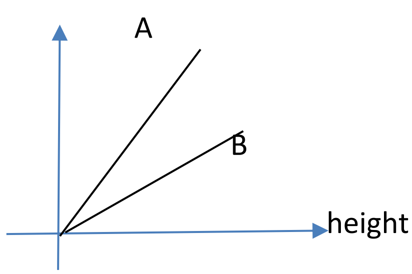


Shape A

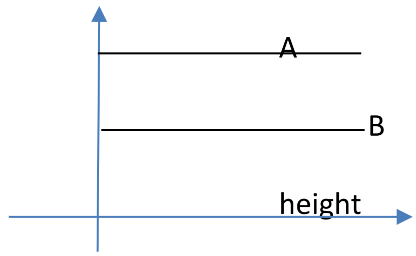


Shape B

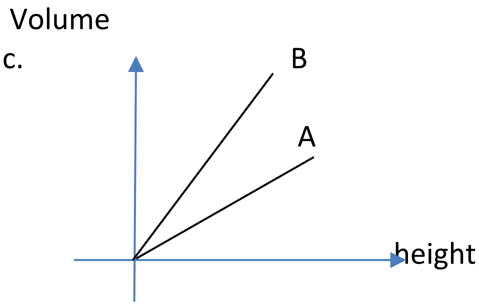
a.
Volume



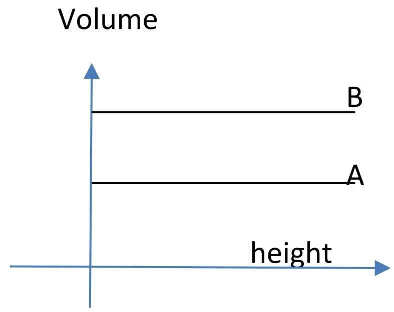
b.
Volume



c.



d.



e. None of these

APPENDIX H: IRB APPROVAL LETTERS

Maricopa County Community College District
2411 West 14th Street
Tempe AZ, 85281
TEL: (480) 731-8701
FAX: (480) 731 8282

DATE:	December 01, 2017	
TO:	Baranowski, Becky, Mathematics	
	Torrison, Levi, Chemistry	
FROM:	MCCCD Institutional Review Board	
PROTOCOL TITLE:	Creation of a calculus concept inventory pre-post test.	
FUNDING SOURCE:	NONE	
PROTOCOL NUMBER:	2017-08-584	
APPROVAL PERIOD:	Approval Date: December 01, 2017	Expiration Date: November 30, 2018
FORM TYPE:	NEW	
REVIEW TYPE:	FULLBOARD	

Dear Principal Investigator,

The MCCCD IRB reviewed your protocol and determined the activities outlined do constitute human subjects research according to the Code of Federal Regulations, Title 45, Part 46.

The determination given to your protocol is shown above under Review Type.

You may initiate your project.

If your protocol has been ruled as *exempt*, it is not necessary to return for an annual review. If you decide to make any changes to your project design which might result in the loss of your exempt status, you must seek IRB approval prior to continuing by submitting a modification form.
If your protocol has been determined to be *expedited or full board review*, you must submit a continuing review form prior to the expiration date shown above. If you make any changes to your project design, please submit a modification form prior to continuing.

We appreciate your cooperation in complying with the federal guidelines that protect human research subjects. We wish you success in your project.

Cordially,
MCCCD IRB

MCCCD IRB

From: lori.thorpe@domail.maricopa.edu

Sent Date: Tuesday, October 01, 2019 12:02:37 PM

To: rebecca.baranowski@estrellamountain.edu, levi.torrison@estrellamountain.edu

Cc:

Bcc:

Subject: IRB Protocol Approved: 2017-08-584, Baranowski, Becky

Message:

IRB has approved the protocol with the following details.

Protocol ID: 2017-08-584
Principal Investigator: Baranowski, Becky
Department: Mathematics
Protocol Title: Creation of a calculus concept inventory pre-post test.
Review Type: FULLBOARD
Approval Date: October 01, 2019

You can print or download an Approval Letter for your protocol by going into the Event History link of your application.

FERRIS STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD FOR HUMAN SUBJECT RESEARCH
1010 Campus Drive FLITE 410 Big Rapids, MI 49307 | (231) 591-2553 | www.ferris.edu/irb

Date: September 26, 2019

To: Susan DeCamillis
From: Gregory Wellman, R.Ph, Ph.D, IRB Chair
Re: IRB Application for Review

A reliance agreement has been put in place between the Ferris State IRB and **Maricopa County Community College District (MCCCD) IRB** which governs this study; Ferris State IRB is relying upon the approval determination of MCCCD IRB as an Expedited project with an **expiration date of November 13, 2019**. It is your responsibility to ensure and inform the FSU IRB that all necessary institutional permissions are obtained from MCCCD IRB and that all policies are met prior to beginning the project, such as documentation of institutional or department support. Approval applies only to the activities described in the protocol submission; should revisions need to be made, all materials must be approved by MCCCD IRB prior to initiation and submitted to Ferris IRB for our records. In addition, each IRB must be made aware of any serious and unexpected and/or unanticipated adverse events as well as complaints and non-compliance issues.

As mandated by Title 45 Code of Federal Regulations, Part 46 (45 CFR 46) you are required to submit an annual review during the life of the research project and a Final Report Form upon study completion. Thank you for your compliance with these guidelines and best wishes for a successful research endeavor.

Regards,

Gregory Wellman, R.Ph, Ph.D, IRB Chair
Ferris State University Institutional Review Board

APPENDIX I: RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

Calculus Concept Inventory
Pre-Post Test

Faculty Sponsor: Rebecca L. Baranowski Email:
rebecca.baranowski@estrellamountain.edu Phone: **623-935-8596**

DESCRIPTION OF THE RESEARCH

You are invited to participate in a research study, which involves the creation of a calculus pre-post test. You have been asked to participate because you have knowledge of calculus. The purpose of the research is to create questions that are worded clearly and appropriately. The 2nd purpose is to create the most appropriate distractors for the multiple-choice parts to inform faculty of what the student misconception for the concept may be. The 3rd purpose is to create this pre-post test so that faculty can gain useful information regarding their teaching practices. Faculty will be able to use the information to determine whether activities, lectures, homework, and other class projects are useful in student learning.

WHAT WILL MY PARTICIPATION INVOLVE?

Participation in this will involve either interviews (60 minutes) or taking the pre-post exam (30 minutes). People who are interviewed will assist with wording of questions and provide feedback on distractors. Data collected from people who take the pre-post test will be analyzed to determine if the distractors are relevant and whether the information provides faculty feedback about his or her teaching pedagogy. For example, does the data help faculty make changes to their teaching to help improve student learning in calculus?

ARE THERE ANY RISKS TO ME? This study has only minimal risks. Participation or non-participation will not have any impact on student grades.

ARE THERE ANY BENEFITS TO ME?

Benefits include assisting instructors improving pedagogy. You may contact the researcher at the end of the semester if you are interested to learn more about the study's outcome.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

This study is confidential. Neither your name nor any other identifiable information will be recorded. Since the study is confidential, participation or non-participation will not impact student grades.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?

You may ask any questions about the research at any time. If you have questions about the research after you leave today you should contact the Principal Investigator Rebecca Baranowski at 623-935-8596. If you have concerns about how the research was conducted, you may also call the district IRB office at (irb_office@domail.maricopa.edu) or (480) 731-8701.

Your participation is completely voluntary, and you have the right to withdraw from the study at any time. If you decide not to participate or to withdraw from the study at any time, there are no penalties.If you are under the age of 18, please don't participate in this study. Please feel free to ask any questions about your participation in this research and consent to participate. You will receive a copy of this form for your records.

Participant Printed Name:________________________________

Participant Signature:_________________________________ Date:_________________________