Formative Assessment in Introductory Calculus

One of the most pressing problems in higher education is that there are not enough science, technology, engineering or mathematics (STEM) majors in US universities graduating to meet the demands of the industry. This lack of STEM graduates is mostly caused by students leaving STEM degrees after introductory calculus (Bressoud, Rasmussen, Carlson, & Mesa, 2014). Because of the lack of efficiency of traditional calculus instruction, students leave their STEM majors to pursue fields of study that they perceive to require less effort in return for an acceptable amount of success (Ellis & Rasmussen, 2014; Oehrtman, 2009).

The oldest, most common alternative to traditional calculus curriculum is the Treisman Model. This model suggests that students learn best when calculus is taught similar to a science class: with both a lecture and a lab (Treisman, 1992). However, more recent research suggests that these labs should cover a single theme (limits) and mirror successful students' actual learning processes (Oehrtman, 2009). Further research indicated that most students benefit from pre- and post- lab activity (Dibbs, 2014).

However, the pre- and post- labs are a far stronger predictor of students' success than their weight in the course grade would indicate. This suggests that the pre- and post- labs are measuring something about students other than calculus knowledge. One possible explanation for this effect was that students who completed more post-labs had different mindsets about learning mathematics than those that did not. It has been noticed that mindsets play a significant role in the overall success of calculus students. Dweck (2007) defines mindset in two different ways: fixed mindset and growth mindset. Students classified under the fixed mindset, if not immediately successful in introductory calculus often leave the STEM field. However, growth mindset students can persist and succeed, even after failures as severe as failing a course (Dibbs, forthcoming). This study will identify students' mindsets and monitor their success in a CLEAR Calculus classroom.

A recent study found that all students who participated in CLEAR Calculus, the limit approximation calculus labs described in Oehrtman (2009), became more growth oriented by 1.6 standard deviations; this suggests that the curriculum itself, not the post-labs, is likely to be responsible for this positive mindset change (Dibbs, 2015).

I am going to examine how this particular curriculum supports large, positive mindset changes in students through formative assessment such as pre- and post-labs. This research will be guided by utilizing the research question: What are the features of CLEAR Calculus that promote positive changes in students' mindsets?

This topic is important because if we know what causes students the most success, we can alter the traditional calculus instruction methods to produce more effective calculus students. By understanding what makes CLEAR Calculus effective, it provides a strong argument for using this curriculum, and interested practitioners who are not willing to implement CLEAR Calculus can learn what components to add to their classes if they want they would like to see a positive increase in their students' mindsets.

In order to investigate this research question, I will perform a mixed methods case study (Patton, 2002). A key component of the study will be the participants' mindsets. To measure this, a commercial survey instrument—the Patterns of Adaptive Learning Scale, called PALS—will be used that will identify and measure students' mindsets. The focus of my study will take place in a non-traditional, CLEAR Calculus classroom. The students in this class will be primarily second semester freshmen students with little to no post-secondary mathematical background.

Prior to designing a study, it is important to understand the research preceding the study relating to my question. The next section provides a synthesis of the recent research on this topic.

LITERATURE REVIEW

There are several major topics related to the research question of this study: problems with traditional calculus instruction, the evolution of CLEAR Calculus, and formative assessment. After discussing each of these topics in turn, the literature review concludes with my researcher stance.

Obstacles in Calculus: Ellis & Rasmussen

Of the 600,000 first-year college students that take Calculus I, 250,000 of them fail in the first semester (Treisman, 1992). Fourteen years later, Ganter (2006) confirmed the calculus failure rate to be 40-60%. Treisman (1992) speculated as to why there are such low success rates among introductory calculus courses. As a result of failing introductory calculus, students pursuing a STEM degree often leave the field citing the lectures were traditional and uninspiring, encouraging memorization instead of comprehensive application and understanding (Seymour, & Hewitt, 1997).

However, an alternative instruction method has the potential for deeper comprehension and better appreciation of the subject (Treisman, 1992). By engaging the class in a lab-based structure, encouraging group work and whole-class discussions, students are more likely to retain information (Ellis & Rasmussen, 2014). Formative assessment can be utilized in the form of the CLEAR Calculus curriculum to ensure this retention among students (Oehrtman, 2009). Hutcheson, Pampka, and Williams (2011) found that students use the instruction experience of their first year of mathematics courses to decide to continue or discontinue their pursuit of a

STEM degree. This is why a strong curriculum that fosters comprehension and understanding is vital.

Many US universities utilize first year courses in STEM fields to discourage an overpopulation of students pursuing these degrees (Steen, 1988; Wake, 2011). It is important that students are successful in completing a STEM degree for many reasons. According to the US Presidents Council of Advisors on Science and Technology (PCAST, 2012), economic growth can be traced to an increased number of students entering the STEM field. Without US STEM graduates, the job market—and by extension, the economy—will suffer greatly.

The Evolution of CLEAR Calculus: Calculus Reform Treisman & Oehrtman

The major area of research in mathematics education in the 1990's was the problem with introductory college calculus reform (Oehrtman, 2008). The most successful calculus reform to emerge from this reform movement was the Treisman Model of instruction (Ganter, 2006). The Treisman model emerged to address several problems in a traditional calculus course; the main problem being that students were more interested is passing calculus than they were in understanding the mathematics taught (Treisman, 1992). Although professors believed that the high failure rate was due to students' low income, low motivation, poor academic preparation and lack of family support, further investigation revealed that that this was not the case (Treisman, 1992). Longitudinal studies at the University of California-Berkley revealed that students who were successful in calculus were so because they learned how to work and study in groups effectively, while students that failed were found to have worked alone, eventually becoming frustrated, and then quit trying (Treisman, 1992).

The Treisman classroom model is designed to train all students to become effective group members in mathematics. The current iteration of the Treisman model used today is called

CLEAR Calculus, which is a refinement of the original Treisman model based on the approximation framework (Oehrtman, 2008). According to Treisman, calculus instruction today does not teach problem solving in a way that promotes the development of generalized problem solving skills. Instead, departments are teaching students how to excel in routine computations rather than how to comprehend the subject matter (Treisman, 1992). The needs of the students were not being met, and Treisman was determined to find a way to facilitate calculus comprehension rather than calculus regurgitation.

However, even when students are taught with the Treisman model, many students have a great difficulty in articulating mathematical concepts (Oehrtman, 2008). Oehrtman believed mathematical careers should require much of students in the area of proof engagement and argumentation (Oehrtman, 2008). Students should be able to comprehensively defend mathematical theories by the end of their schooling. Traditional calculus instruction provides most students with a very superficial understanding of mathematical procedures, whereas it may equip only a few for further studies (Oehrtman, 2008).

Upon entering Calculus I, students have no conceptual structure to comprehend the most basic components of calculus due to their lack of prior exposure to the content. Oehrtman (2008) suggests a solution that would aid students with their comprehension: engagement in multiple activities that reveal and encourage the abstraction of a common structure. By presenting all calculus concepts through a similar framework, students develop a more organized understanding of limits than they do in a traditional calculus course (Oehrtman, 2009). CLEAR Calculus achieves this through formative assessment (pre- and post- labs). In a typical lab, students are asked to approximate the water pressure of a dam (Figure 1). The first row would represent the pre-lab. Students are required to find the approximating by drawing a picture, graphing the data, finding the value algebraically, and again numerically (Oehrtman, 2008).

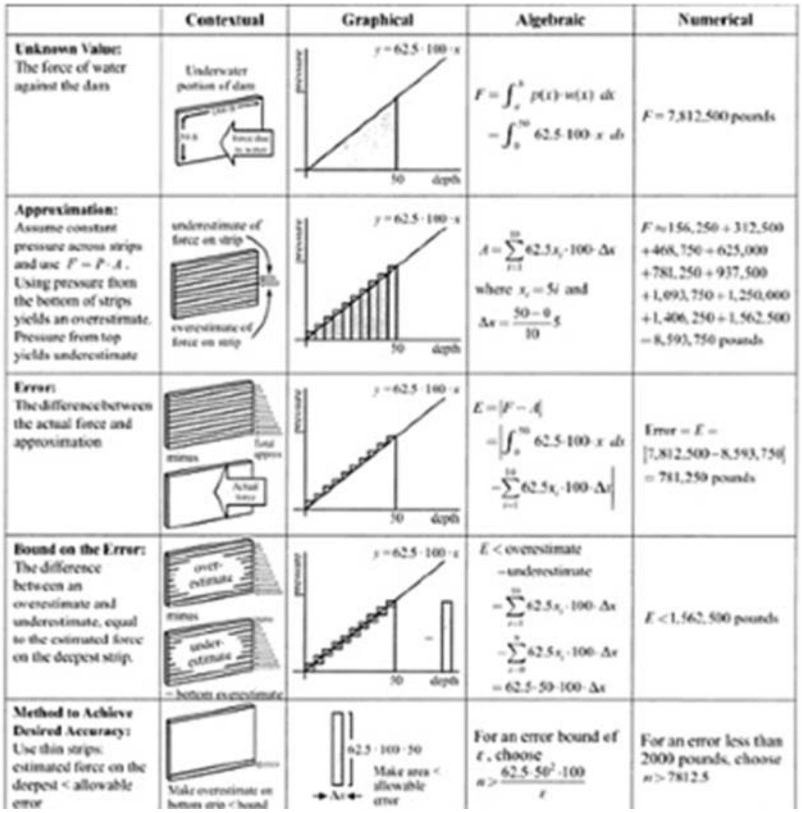

Figure 1. Typical CLEAR Calculus lab

Formative Assessment

During the CLEAR Calculus labs—such as the one described in the previous section—the instructor walks about the classroom conducting informal formative assessment, guiding the students through the labs; the pre- and post- lab assignments are considered written formative assessment. Although prior research does not indicate formative assessment is the cause of students' mindset changes (Dibbs, 2015), research on non-cognitive factors involved with students' learning indicate that the use of formative assessment in the classrooms help students perceive their teacher as caring about them (Dibbs, 2014) and encourages them to take ownership of their own learning (Black & Wiliam, 2009). This makes formative assessment an important structural component of CLEAR Calculus.

Black and Wiliam (1998) define formative assessment as teaching to meet students' academic needs (Black and Wiliam, 1998). After research and testing in the United Kingdom, Black and Wiliam (1998) have proven how formative assessment is essential in the raising of achievement standards in schools. Teachers play a large role in a students' success. It is very important for teachers to be aware of their students' strengths and weaknesses in learning, so that they can teach on the appropriate level (Black and Wiliam, 1998). The key component to formative assessment is the adaption of teaching to meet student needs (Black and Wiliam, 1998). By building on the successes of traditional instruction and reforming the less profitable practices, Black and Wiliam (1998) have created more efficient teaching methods through formative assessment in K-6 British children.

Formative assessment has been proven to assist low achievers more so than high achievers. This has aided in the reduction of the range of achievement with an overall higher standard. When teachers become aware of their pupils' needs and begin to address those needs, a positive change has occurred in the classroom. Unfortunately, many teachers are out of touch with the amount of understanding the students are experiencing, therefore their teaching practices are inefficient (Black & Wiliam 1998; 2009).

The way students' perceive themselves is very important. If a student identifies his or herself as unable to learn, there begins to be a decrease in the seriousness they take in school (Black and Wiliam, 1998). This is more likely to happen to a student of the fixed mindset, because when confronted with a failure, students with fixed mindsets tend to retreat from the problem. Fixed mindset students with high confidence in the subject matter often have high persistence and seek challenges. However, if a fixed mindset student has low confidence in his or her ability to succeed, they may display a low persistence. Often, students that receive low marks will continue the same behaviors, consistently receiving low scores. Many students are simply content to put forth the minimum effort that will be accepted. Students do so by avoiding difficult tasks – looking for clues and patterns to find the right answer without actually learning the material.

Students of the fixed mindset may find Calculus I difficult if they do not initially understand it. The fixed mindset person believes that smartness cannot be obtained—it cannot be gained or lost; one either has the capacity (or potential?) to master a topic or not (Dibbs, 2012). Calculus I curriculum may be difficult to that of a fixed mindset because the student will not have entered the class with prior knowledge of the subject; he or she will be required to learn the new material. It is common for fixed mindset students—who have been successful in their school career—to drop Calculus I after the first test if they have been unsuccessful in the class. This is a pivotal point in the fixed mindset students' academic career; many students change their major from that of a STEM field following the failure or drop of their introductory calculus course because they believe they are not mentally equipped to succeed.

Growth mindset students often do poorly in the beginning of the semester, but what sets these students apart is the changes they make in their studying/note-taking after failure. The expectation is that these students will find more efficient ways to approach the class that will ensure learning and ultimate success.

Black and Wiliam (1998) believe that the classroom is lacking a culture of success; simply assigning students grades is overemphasized, whereas advising students is underemphasized. When grades are assigned, this quantitative data can be used to accurately gauge the placement and success of a student in a class, but more is to be gained when academic advising from a teacher takes place (Black and Wiliam, 1998). Unfortunately, standardized testing in US high schools often dominates teaching and assessment. Black and Wiliam (1998) states that testing does not provide teachers with an adequate model for formative assessment. Feedback improves learning when it shows the students their strengths and weaknesses without a number grade attached to it (Black and Wiliam, 1998).

If pupils are to benefit from formative assessment, they should be trained in self-assessment so that they might comprehend what is needed to achieve success (Black and Wiliam, 1998). This can be facilitated by discussions in which students are to articulate their own understanding of the concept. This is beneficial to not only the student sharing, but also the students struggling with similar concepts. This kind of alteration of the original lesson plan is an investment of sorts. Teachers must invest time in their students to create a culture of questioning and deep thinking (Black and Wiliam, 1998).

Black and Wiliam were quite thorough in their research; however their study focused on British children grades K-6. Dibbs (2014) examined Black and Wiliam’s theoretical framework to see if it crossed age and cultural barriers. It did, but there were inconsistencies with post-lab results. Though it appeared as if the inconsistencies were related to mindsets, it was revealed that changes in mindsets are most likely fostered by CLEAR calculus instruction rather than post-labs (Dibbs, 2015). This thesis project will connect the previous work on mindsets and calculus by generating hypotheses about how CLEAR Calculus helps students make positive mindset changes.

Research Stance

When qualitative research is done, it is vital to disclose the researcher's experience and expectations in the area of research so the reader understands where the writer stands on the topic.

I studied Calculus I, II, and III in a traditional classroom setting. In addition to attending class, I was also involved with the Texas A&M University-Commerce Calculus Bowl Team. This experience allowed me to have a larger exposure to calculus than the average calculus student. Regarding the pre- and post- labs, I have no personal experience. The only exposure I have had with formative assessment is casual conversation with classmates currently taking a nontraditional calculus course.

In Calculus I, I struggled with the material. I did not immediately grasp the concepts presented; this was a novel and unpleasant experience. When I realized that I did not know the material as well as I would have liked, I spent hours studying each chapter in preparation for the assignments and tests. I received a B in the course, but I earned that B. I had to use the growth mindset to find more effective ways to study efficiently. My inner fixed mindset was saying, "If you can't get it the first time, you're not smart enough. Just give up."

Calculus II was a similar experience to Calculus I, except the material was more difficult, requiring more hours of studying for comprehension. In order to gain more experience and exposure to the material, I joined the Calculus Bowl team and Math Club to strengthen my calculus skills by surrounding myself with math intellectuals that shared similar misunderstandings of the material. This consisted of weekly evening practices that lasted for two hours. During these practices, we were presented with up to fifty calculus problems with content taken from Calculus I and Calculus II classes. These problems were to be solved in 60 seconds or less; precision and speed were a must. By participating in the Calculus Bowl, I increased my exposure to regular classroom material.

During this study, I expect to encounter students with varying backgrounds in Calculus. College Algebra and/or Pre-Calculus classes are prerequisites to introductory Calculus at this institution. Students are expected to be of the semi-fixed mindset immediately following Calculus prerequisite courses, because these courses require significantly less floundering to demand a change in mindset to earn a satisfactory grade. Upon entering introductory calculus, students are expected to have little to no understanding of limits, and struggle with complete comprehension of topics. In addition, it is expected that post- College Algebra/Pre-Calculus students will struggle with trigonometric functions.

I will use the knowledge I gained from my own calculus experiences to provide me with an understanding of potential biases as I assess students that participate in this study. Understanding my stance about the research allowed me to design a study that would provide a check on these potential biases. In the next section, I will explain the learning theory I used to structure student responses.

Theoretical Perspective

Before qualitative research is conducted, one must define the major constructs in the research question as well as define what learning means within the context of the research. After discussing which learning theory I will use in this study, the remainder of this section explores the concept of mindsets in greater detail.

Epistemology

In order to frame participant's responses, it was important to choose a learning theory. The theory chosen was Vygotsky on social constructivism. Vygotsky's research, interpreted by

Gredler and Shields (2008) found that all knowledge is constructed in a social setting. This theory claims two major components (Gredler & Shields, 2008). The first component is informal knowledge – knowledge gained implicitly by observation (i.e. monkey see: monkey do), also known as spontaneous knowledge (Gredler & Shields, 2008). One might not be able to articulate why he or she knows a concept learned through spontaneous knowledge, however they are able to put it into practice. An example of this is the term "brother." To a small child, he or she may be able to tell you if a person is their "brother" or not, but they would not be capable of defining what a "brother" is.

The second component to Vygotsky's theory is formal knowledge (Gredler & Shields, 2008). This is knowledge explicitly taught (i.e. calculus content). This component, also referred to as scientific knowledge, takes form as factual knowledge that one may be able to implement, but may not understand the reasoning behind it (Gredler & Shields, 2008). For example, Algebra I students are taught the mathematical mnemonic of FOIL. The students may be able to walk themselves through each step of the process, but they have no understanding of what they are doing, why it works, or whether it is relevant or not.

Informal knowledge is not inferior to formal knowledge, but rather it is learned differently. Ideally, one must have both. This theory fits my study because I am looking for students' spontaneous knowledge about their mindsets in the context of math classes with lots of scientific knowledge; Vygotsky captures both of these concepts. Mindsets

Theoretical Perspective

Carol Dweck's *Mindsets* (2006) showed that students' learning patterns fall under two very different categories: the fixed mindset and the growth mindset. Dweck found in her research that a student's mindset has a very large influence on the students' success in a difficult class, such as Calculus I (Dweck, 2006). This section will explore the differences in two theories of intelligence: fixed and growth mindsets.

The growth mindset primarily focuses on recovering from and learning from one's failures for future improvement. However, the fixed mindset places much value on immediate success; if a fixed mindset student believes he or she has a significant chance of failure, there will often not be an attempt of the task, assignment, class, etc. In her research, Dweck (2006) observed that the way a student perceives his or herself strongly affects the way they leads their life.

Dweck (2006) discovered that the students that appear to be the most intelligent at the beginning of the semester might not always end the semester as the smartest. In a Calculus classroom, fixed mindset students may begin the semester as the smartest; however, when the coursework becomes difficult or if they find themselves failing – they give up. That's when the growth mindset students seek ways to improve their methods, learn from their failures, and begin excelling in the class. The growth mindset students often end the semester with the label "smartest" because of their persistence (Dweck, 2006).

Motivation is the overarching difference in these mindsets – what drives a student is how they're going to react to failure. For instance, consider a class of 7^{th} grade students is given a math exam where the overwhelming majority of the class fails. The fixed mindset students prepare for the next test by studying less – they could not do well on the first test, so they see no reason to try on the second. These students are under the fixed mindset belief that "smarts" are not to be gained; you either have the ability or you do not. However, the growth mindset students make a greater effort to do well on the next test by studying harder and more efficiently. When the second test is administered, the growth mindset students that spent extra time preparing for the second test excel well beyond those of the fixed mindset students that refused to study (Dweck, 2006).

The fixed mindset student feels the constant need to be superior – which means failure is not an option. When they feel as if they are superior to others, they feel smart. Their view is that "effort can reduce you" (Dweck, 2006) – why attempt something if failure is an option? They believe that only "dumb kids work hard in school. Is it better to fail on purpose than to try and show that you are dumb?" Fixed mindset students are prone to attempt only tasks that they are apt to succeed in; this allows for very high achievers. Many Honors College, Top 10% overachievers, and first semester STEM majors often have the fixed mindset. However, upon taking Calculus I, they do not experience immediate success. This unexpected difficulty (or failure) often discourages the fixed mindset students from continuing in their chosen STEM field (Dibbs, 2014; Dweck, 2006).

In a Chemistry class, fixed mindset students were found to stay interested when they did well right away. However, if they were not successful from the start, they grew disinterested and distant (Dweck, 2006). These students were only engaged when they believed they would succeed. Dweck discovered that fixed mindset students have very low calibration, meaning they are often inaccurate when judging their own abilities (Dweck, 2006).

Dweck defines the growth mindset as someone that can grow and change through application and experience. Students with the growth mindset view failure as a gift, an opportunity to get better. If not immediately successful, they don't believe they are failing; they believe they are learning. Each student's definition of failure plays a vital role in whether or not the student has a fixed or growth mindset. Dweck (2006) describes the growth mindset as unique students converting obstacles in life into future successes. Differing from fixed students, growth mindset students often have very high calibration; they are more realistic in self-assessment (Dweck, 2006). This is often helpful in the classroom as they assess the amount of learning that has taken place.

In summary, students' mindsets play a significant role in the outcome of their overall classroom experience (Figure 2). Over time, students have been observed changing their mindset due to structure changes in the classroom (Dibbs, 2014). Formative assessment has been a crucial tool in facilitating a classroom environment conducive to positive mindset changes.

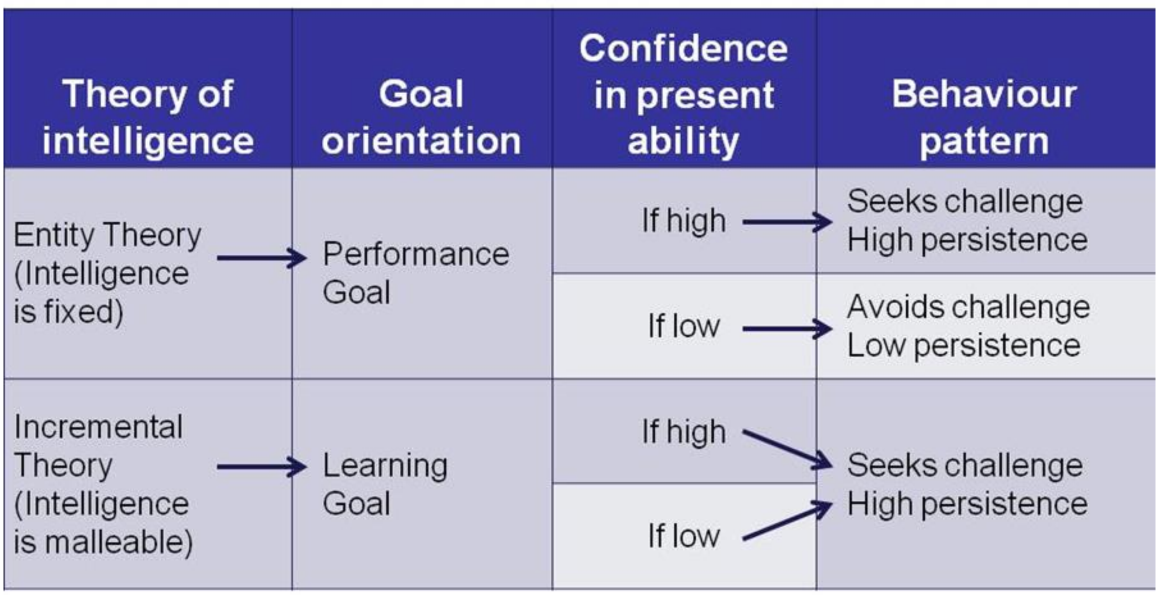

Figure 2. Summary of Mindset theory

METHODS

The following describes the methods I will use to find an answer to the research question "What are the features of CLEAR Calculus that promote positive changes in students' mindsets?" I will identify the setting the study will take place, as well as discuss the data sources, handling, and analysis.

Setting. This study will take place at a midsized rural master's comprehensive regional university in the South with approximately 11,000 students. There are 40.6% of the students at this university who are non-white, and 60.3% are female. The students who will participate in this study will be enrolled in introductory calculus in the Fall 2015 semester. The students enrolled in introductory calculus are most often mathematics, physics, and engineering majors.

Data Sources. I will select an introductory calculus course of primarily first-year STEM majors to conduct my pilot study. During the first three weeks of the semester, I will obtain research consents from the participants and administer a PALS study to assess initial student mindsets. Upon reviewing the PALS results, I will select up to ten students with trends in their mindset score to obtain a sample of maximum variation (Patton, 2002). The chosen students will receive a letter asking for their participation in a brief interview. I will interview until data saturation is reached (Patton, 2002), and then select the three most interesting cases for analysis in my thesis.

Upon their consent, I will conduct semi-structured interviews to gather our qualitative data regarding the effects of formative assessment in student learning. The following is an example of some sample interview questions we will use to conduct the interviews:

1. Tell me what your studying/note taking habits have looked like in previous math courses.
2. How well do you do in class? Why?
3. Is it important to you to be seen by your peers as smart?
4. Do the new labs seem difficult?
5. How does procrastination affect your pre- and post- labs?
6. Why do you believe you do labs?

Data Handling

Students will be assigned ID and pseudonyms numbers at the beginning of the study to ensure anonymity and that will also be published in the research. The key containing the students’ ID and pseudonyms will be kept in Dr. Dibbs’ locked office to ensure security and confidentiality. Once ID numbers and pseudonyms have been issued, students’ real names will not be looked at again, and the key will be discarded at the end of data collection. Upon being selected to participate in the interview process of this study, students will be invited to participate via invitation letter.

Data Analysis

Data analysis for the thesis will be conducted in two phases. First, I will conduct a pilot study that will allow me to develop an analysis scheme for the main project. The data for the pilot has been collected and will be analyzed this summer. The coding scheme that emerges from the pilot data will be used as standards of evidence for a top-down coding (Patton, 2002) of the interviews from the students participating in the thesis project.

Trustworthiness

In an effort to protect against bias and ensure research was conducted rather than expectations being confirmed, it is important to have checks and balances in place for this thesis project. Dr. Dibbs and myself will perform the data analysis independent of each other using an agreed upon chart. We will reconcile our codes to verify consistency.

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