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Exploring the Relationship Between Course Structures and Student Motivation in Introductory College Calculus: A Self-Determination Theory Perspective

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EXPLORING THE RELATIONSHIP BETWEEN COURSE STRUCTURES AND
STUDENT MOTIVATION IN INTRODUCTORY COLLEGE CALCULUS:
A SELF-DETERMINATION THEORY PERSPECTIVE

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Engineering and Science Education

by
Paran Rebekah Norton
May 2020

Accepted by:
Dr. Karen High, Committee Co-Chair
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Abstract

Calculus I occupies a gatekeeper role for STEM majors nationwide. The Mathematical Association of America (MAA) investigated this issue and found that the use of active learning strategies was one important characteristic of successful calculus programs across the country. This sequential explanatory mixed-methods study explores this issue further by examining the relationship between student motivation and course structures for introductory calculus. Calculus I course structures with differing levels of active learning were examined. The theoretical framework of self-determination theory (SDT) guided this study, which defines three basic psychological needs that are essential to fostering students’ motivation: competence, autonomy, and relatedness.

The quantitative phase of this study consisted of analysis of student survey data to investigate the difference in students’ perceptions of these motivational components between the three course types (traditional lecture, large active learning, and hybrid online). The findings showed that students in the hybrid online course had significantly lower autonomy, competence, and relatedness perceptions, as well as lower autonomous motivation scores, compared to the traditional and large active learning courses. Next, students were purposefully selected based on the survey results to participate in semi-structured interviews with two members of the research team. The qualitative analysis of our interview data revealed specific aspects of each course type that were contributing to students’ perceptions of their competence, autonomy, and relatedness. Specifically, the large active learning course structure provided the most opportunities to support students’ motivation. Implications for mathematics faculty include incorporating active learning
experiences in the classroom, since this study revealed that having opportunities to consistently interact with their peers and the instructor supported students’ basic psychological needs.
Dedication

I dedicate this work to my Lord and Savior, Jesus Christ.

For thine is the kingdom, and the power, and the glory, for ever. (Matthew 6:13, KJV)
Acknowledgments

Thank you to my family for your unconditional love and support throughout this journey. I would like to thank my husband, Baynes, for being my best friend and always being by my side. I would like to thank my father for the many phone calls, being a sounding board for my ideas, and sharing your knowledge and experiences as a researcher. I would like to thank my mother for being my cheerleader, cleaning my house, and buying me snacks. I would like to thank Terry for his prayers and encouragement. I would like to thank my sister Chloe for always believing in me.

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I also thank everyone in the ESED family. I could not have done this without your support and friendship over the years. I especially want to thank Shannon and Victoria for their constant encouragement. I thank Steven for all of his help with this study.

I also want to thank Ben Wiles for sharing with me his insights and research about self-determination theory and student motivation in mathematics courses.

I want to thank Ali for always being there for me during this journey. Your friendship is a blessing.

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I would like to thank the School of Mathematical and Statistical Sciences for their support and direction for this project. I am also very thankful for their support as I completed this work while starting a full-time position in the department. Thank you, Pat and Kevin.

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Chapter 1

Introduction

1.1 Background

Introductory calculus serves as a gatekeeper course to STEM majors across the nation (Bressoud, Mesa, & Rasmussen 2015, Suresh 2006). In addition to having a high failure rate, students who are not successful in this course tend to switch out of a STEM major (Moore 2005). Since our nation is in need of more STEM graduates entering the workforce in order to sustain our global competitiveness, this presents an issue worth investigating (Olsen 2012). Furthermore, students are leaving introductory calculus with less enjoyment and confidence in mathematics. Students at research universities are showing the greatest loss in these two factors (Bressoud et al. 2013).

The Mathematical Association of America (MAA) national study of *Characteristics of Successful Programs in College Calculus (CSPCC)* investigated this issue by looking at characteristics of introductory calculus courses that were impacting students’ attitudes and performance. Findings from this study showed that pedagogical factors had a significant relationship with student attitudes, and the authors suggested that use of student-centered pedagogies and active learning strategies was one important characteristic of successful calculus programs (Bressoud & Rasmussen 2015). These forms of instruction, which are deemed as “ambitious” teaching in the MAA study, are “consistent with instruction that is often referred to as active learning…” (Bressoud et al.
According to Prince (2004), active learning refers to “instructional methods that engage students in the learning process” and is often “contrasted to the traditional lecture where students passively receive information from the instructor” (Prince 2004, pg. 223).

This nationwide issue of a high failure rate for introductory calculus had also been seen at our university in recent years. This introductory calculus course at our university is a single semester Calculus I course. This challenge sparked a large multi-departmental study within our university to investigate the impact of various policy changes on Calculus I DFW rates, where DFW denotes the proportion of students receiving a D or F grade or withdrawing from the course. One of these policy changes included implementing an active learning instructional model. Results from this initial study revealed that the DFW rates were lowest when the department implemented this model, which is discussed in Chapter 2.

Since this initial study revealed a significant reduction in DFW rates associated with using an active learning instructional model, I decided to conduct a pilot study to gain more insight into students’ experiences in different course structures by interviewing a subset of Calculus I students in Fall 2017. I was specifically interested in understanding what affective factors were underlying this improved performance and how these factors were supported by the different course types. Sections of Calculus I were purposefully selected by consulting with faculty members in the mathematics department. Two sections of a large active learning class and two sections of a traditional lecture class
were selected. Twelve students, six in each course structure, agreed to participate in the study.

At this phase, the pilot study was being informed by math identity literature. Specifically, the theoretical framework that includes the constructs of students’ interest, recognition, and performance/competence beliefs (Cribbs et al. 2015). In this framework, interest is defined to be “a student’s desire or curiosity to think about and learn mathematics,” recognition incorporates “how students perceive others to view them in relation to mathematics,” and the performance/competence construct includes “student’s beliefs about their ability to understand mathematics and their beliefs about their ability to perform in mathematics” (Cribbs et al. 2015, pg. 1052).

During the analysis phase, it did not appear that this math identity theoretical framework was fully distinguishing students’ experiences in the two course structures. In terms of the Q3 framework for quality assurance in qualitative research (Walther, Sochacka, & Kellam 2013), there were issues with theoretical and pragmatic validity, since the math identity framework was not surviving the participants’ realities (see Chapter 4 for a full discussion of qualitative research quality). Particularly, students’ interest level and feelings of recognition did not seem to have a meaningful relationship with the course structure, whereas their performance/competence beliefs did appear to have some relationship with the course structure. Specifically, the large active learning course appeared to support performance/competence beliefs more than the traditional lecture course. Hence, the use of the math identity lens alone could prevent seeing the full
extent of students’ realities in these two classrooms since it was only capturing one aspect that was distinguishing their experiences.

Thus, at this step in the pilot study, I revisited the math identity literature to explore other frameworks that could better capture my participants’ social realities. This led me to consider the math identity framework by Cobb, Gresalfi, and Hodge (2009) and Cobb and Hodge (2011). Their interpretive scheme consists of three constructs: normative identity, core identity, and personal identity. Normative identity is defined as “a doer of mathematics established in a particular classroom” which is focused on the social context of the classroom (Cobb, Gresalfi, & Hodge 2009, pg. 43). This refers to the identity students would have to take on in order to become successful students in their math classroom, which is “reciprocally constituted in interaction and consists of the ways of acting that fulfills others’ expectations” (pg. 44). Within the construct of normative identity are the ideas of the distribution of authority and the ways students can exercise agency in their mathematics classroom.

Core identity is focused on “students’ more enduring sense of who they are and who they want to become” (Cobb & Hodge 2011, pg. 167). Cobb and Hodge (2011) explain that each student has experiences of participating in various communities where they have had incidents of “presenting themselves and being recognized in particular ways, some of which have recurred” (pg. 189). Thus, core identity is a more long-term view of a student’s identity. Core identity is the aspect of identity that Cribbs et al. (2015) base their model for mathematics identity on, which includes the constructs of interest, recognition, and performance/competence.
Lastly, personal identity is “concerned with who students are becoming in particular mathematics classrooms” (Cobb & Hodge 2011, pg. 190). The authors state that students’ development of personal identities in specific classroom settings can influence their core identities over time. The types of personal identities students can develop in a certain math classroom are similar to the different types of motivation described by self-determination theory (Cobb & Hodge 2011). This finding led me to revisit the literature once more and specifically focus on self-determination theory. Upon further analysis of my pilot interviews, the themes emerging from the data were aligning better with key constructs from self-determination theory (SDT) (Deci & Ryan 2000). The data was interpreted through this new lens since it better encompassed the social reality under investigation.

During this time, I also attended a seminar about best practices in the “construction of sustainable, motivationally-supportive mathematics learning environments in higher education” (Wiles 2018). In this presentation, Wiles discussed using self-determination theory constructs to investigate differences in student motivation between traditional lecture and more collaborative learning environments. The knowledge I gained from this seminar helped to solidify my choice in using self-determination theory as the theoretical framework for my dissertation study, since this lens revealed how students’ experiences were differing in these two course types, thus affecting their motivation.
1.2 Literature Review

Self-Determination Theory

The *framework of self-determination theory* (SDT) guided this study. Self-determination theory is a macro-theory of human motivation that was developed by psychologists Deci and Ryan. Ryan and Deci (2000) state, “human beings can be proactive and engaged or, alternatively, passive and alienated, largely as a function of the social conditions in which they develop and function” (pg. 68). They stress the importance of doing research on the design of social environments in order to determine the best conditions for optimizing people’s development, performance, and well-being, thus making this an important framework to study classroom structure. As such, SDT has been widely applied in the educational domain. According to SDT, three needs are essential to fostering a student’s motivation and engagement: *competence, autonomy, and relatedness*.

Competence refers to students feeling confident and effective in the classroom. Deci et al. 1991 state that competence “involves understanding how to attain various external and internal outcomes and being efficacious in performing the requisite actions” (pg. 327). Nunez and Leon (2015) add that the need for competence incorporates an individual’s need to “interact effectively with their environment in order to feel capable of producing desired outcomes” (pg. 277). Autonomy, under the SDT framework, does not refer to students being independent, but rather to their feeling that the behavior is volitional instead of controlled (Niemiec & Ryan 2009). In other words, they have a sense of agency and authority. Finally, relatedness incorporates students’ need to feel a
sense of belonging in the classroom. An individual’s need for relatedness is supported when one feels connected with others (Filak & Sheldon 2003, Nunez & Leon 2015).

The need for autonomy can also be broken down into three separate types: organizational, procedural, and cognitive autonomy. Organizational autonomy refers to students being able to have input into the classroom procedures such as selecting due dates or choosing group members or seating assignments. Procedural autonomy support involves students having choice in the form of their work such as choosing the materials for a project. Cognitive autonomy refers to student ownership of their learning. This involves students having opportunities to think through the material on their own and discuss solutions with others (Stefanou et al. 2004). Stefanou et al. (2004) suggest that “cognitive autonomy may be the essential link to increasing not only short-lived involvement, but enduring motivation and engagement” (pg. 101).

In addition to defining the three basic psychological needs described above, self-determination theory goes beyond describing motivation as intrinsic versus extrinsic by distributing motivation along a continuum from autonomous to controlled regulation (Figure 1.1). These different types of regulations are defined by the extent to which the student has internalized a certain behavior. Controlled regulations include amotivation, where the student completely resists and does not value the classroom activities, external regulation, meaning a student participates in order to get a good grade on exam or avoid looking incompetent, and introjected regulation, in which a student engages in classroom activity in order to avoid shame or feel worthy. On the other side of the spectrum is autonomous regulation, which includes identified regulation, integrated regulation, and
intrinsic motivation. Behaviors that are more autonomously regulated have been integrated into a student’s sense of self (Black and Deci 2000). Identified regulation means that the activity is accepted as personally important, such as students studying calculus in order to progress in their major. Integrated regulation is the most autonomous form of extrinsic motivation; as such it is very similar to intrinsic motivation. A student experiencing integrated regulation has fully incorporated a behavior into other aspects of themselves, thus assimilated it into their identity (Deci et al. 1991). For example, a student might study calculus in order to become an engineer and be able to help others, “which is consistent with her abiding values and interests” (Niemiec & Ryan 2009).

Figure 1.1 Self-Determination Theory Continuum (excerpted from Gagné & Deci 2005)

SDT posits that extrinsically motivated behaviors, such as taking a calculus class, can only become autonomously regulated, meaning that the behavior has been integrated into their sense of self, if the social context promotes feelings of competence, autonomy,
and relatedness. In other words, students’ individual motivation is constrained by the norms of the classroom (Goldin et al. 2016). When students’ basic psychological needs are supported by the classroom structure, they are more likely to internalize their motivation to learn (Niemiec & Ryan 2009).

Many prior studies in education, ranging from elementary school to college, have shown the importance of promoting autonomous regulation in the classroom (Deci et al. 1991, Ryan & Deci 2000, Black & Deci 2000, Lavigne, Vallerand, & Miquelon 2007, Trenshaw et al. 2016). In general, more autonomous forms of motivation have been linked to increased interest, excitement, and confidence. This has been shown to lead to higher performance and persistence, even among students with the same level of self-efficacy (Ryan & Deci 2000). Teachers that were supportive of autonomy gave rise to higher levels of students’ perceptions of competence, interest, enjoyment, and performance in an undergraduate organic chemistry course (Black & Deci 2000). Furthermore, high school students that reported higher self-perceptions of competence and autonomy in their science courses had higher levels of intrinsic motivation and identified regulation. This was related to greater intentions to take more science courses and eventually pursue a science related career (Lavigne, Vallerand, & Miquelon 2007). Additionally, students in an undergraduate computer engineering course who were lacking relatedness and competence displayed more external regulation and amotivation (Trenshaw et al. 2016).

Most salient to exploring the relationship between course structure and students’ motivation in a calculus course, Wiles and Levesque-Bristol (2018) studied the
differences in the satisfaction of basic psychological needs and the resulting motivational profiles of students between traditional and collaborative learning environments for Calculus I and II. Results from this study showed that the active learning course promoted students’ needs for autonomy, competence, and relatedness significantly more than the traditional lecture course. In addition, more autonomous forms of motivation were associated with students in the active learning classroom. Overall, students’ perception of satisfaction of basic psychological needs and more autonomously regulated motivational profiles were correlated with higher grades in the introductory calculus courses. The authors call for future quantitative and qualitative research to better understand the specific factors contributing to these differences seen based on course structure.

**Course Structures**

In this dissertation study, I examined the relationship between three different course structures (hybrid, large active learning, and traditional lecture) and student motivation and performance in calculus. The following literature reviews prior studies that have investigated how student outcomes are related to different pedagogical methods.

In a meta-analysis of 225 studies focused on comparing traditional lecture to active learning in undergraduate STEM courses, Freeman et al. (2014) found that failure rates increased by 55% in the traditional lecture classes. Their study also found that active learning increases students’ exam performance by half a letter grade on average. In another review of the literature on active learning, Prince (2004) states that “extensive
and credible evidence suggests that faculty consider a nontraditional model for promoting academic achievement and positive student attitudes” and also suggests that faculty should promote a collaborative environment in their courses (pg. 229).

One particular active learning model that will be discussed further in Chapter 2 is the SCALE-UP (student centered activities for large enrollment undergraduate programs) model. This model is focused on three main pedagogical components which include creating a cooperative learning environment where students are interacting with peers, minimizing lecture time in the classroom, and facilitating the active learning portion of the class by guiding students to the answer, rather than just telling them (Beichner et al. 2007).

Another course type included in this study was a hybrid online course. Hybrid courses involve a combination of both distance learning online and meeting face to face in a classroom setting (Utts et al. 2003). This course structure is also similar to a flipped (Bergmann & Sams, 2012) or inverted (Lage et al. 2000) class, where students learn new content through watching videos outside of class, and class time is spent with students working on various assignments. Bishop and Verleger (2013) conducted a survey of the research regarding the flipped classroom model and found that the results about student perceptions were somewhat mixed, but generally positive. In their review of the literature, they also found that students tended to prefer in-person lectures over video lectures but would rather spend time in class being interactive as opposed to listening to a lecture. A mixed-methods study comparing an inverted and traditional introductory statistics course revealed that students “found it difficult to connect the online and face-
to-face portions of the course” in the flipped course, but were more open to cooperative learning and innovative teaching methods than students in the traditional course (Strayer 2012, pg. 191). A few studies have looked at the flipped classroom model specifically for calculus courses. McGivney-Burelle and Xu (2013) found that students in a flipped section of Calculus II performed better on homework and tests and enjoyed the lecture videos and using class time to solve problems. Sahin et al. (2015) compared flipped versus traditional sections of an engineering calculus course and found that the flipped sections had significantly higher quiz scores than the traditional sections.

Since our course types weren’t perfectly aligned with how these pure course structures are defined in the literature, I conducted classroom observations to better characterize them to see what connections that they had to pure active, lecture or hybrid teaching methods. This is discussed in more detail in Chapters 3 and 4.

1.3 Research Questions

This study is guided by the overarching research question, In what ways do variations in course structure affect aspects of student motivation and performance in Calculus I?

To answer this overarching question, I will answer the following sub-questions in a multi-manuscript format, where Chapter 2 provides background and motivation for this dissertation study, Chapter 3 will address research questions 1.1-1.6, and Chapter 4 will focus on research question 2.
Table 1.1 Research Questions Mapped to Self-Determination Theory

(Course Structures: Traditional Lecture, Hybrid Online, Large Active Learning)

<table>
<thead>
<tr>
<th>Basic Psychological Needs (Competence, Autonomy, Relatedness)</th>
<th>Forms of Motivation (Autonomous vs. Controlled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1.1 What is the difference in student perceptions of their basic psychological needs satisfaction between the course structures?</td>
<td>RQ 1.2 What is the difference in student motivational types between the course structures?</td>
</tr>
<tr>
<td>RQ 1.3 In what ways do students’ perceptions of their basic psychological needs satisfaction change from the beginning to the end of the semester?</td>
<td>RQ 1.4 In what ways do students’ motivational types change from the beginning to the end of the semester?</td>
</tr>
<tr>
<td>RQ 1.5 What is the relationship between students’ basic psychological needs satisfaction and final grade in the course?</td>
<td>RQ 1.6 What is the relationship between students’ motivation type and final grade in the course?</td>
</tr>
<tr>
<td>RQ 2. What aspects of each course structure are supporting students’ basic psychological needs?</td>
<td></td>
</tr>
</tbody>
</table>

Research questions 1.1-1.6 will be addressed by using student survey data from the Basic Psychological Needs Scale (BPNS) (Levesque-Bristol et al. 2010) and the Situational Motivation Scale (SIMS) (Guay, Vallerand, & Blanchard 2000) (see Chapter 3 for a full discussion of the quantitative analysis).
Table 1.2 Research Questions Mapped to Scales

<table>
<thead>
<tr>
<th><strong>Basic Psychological Needs Scale (BPNS)</strong></th>
<th><strong>Situational Motivation Scale (SIMS)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1.1 What is the difference in student perceptions of their basic psychological needs satisfaction between the course structures?</td>
<td>RQ 1.2 What is the difference in student motivational types between the course structures?</td>
</tr>
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<td>RQ 1.6 What is the relationship between students’ motivation type and final grade in the course?</td>
</tr>
</tbody>
</table>

1.4 Research Design

This study employed the sequential explanatory mixed-methods design (Creswell and Plano Clark 2018). I wanted to be able to purposefully select interview participants based on their survey responses in order to gain a range of student perceptions. Additionally, I wanted to pursue findings from the survey analyses in more detail with follow-up student interviews.

In the sequential explanatory design, the first phase consists of collecting and analyzing quantitative data. Then a follow-up qualitative phase is conducted in order to help expand on the results discovered in the quantitative phase. In addition, this design is useful since the quantitative data can give a broad overview of students’ perceptions of their basic psychological needs and motivations in the different course structures as well as how
these motivational components are related to student performance, while the qualitative piece can help explain the meanings underlying those relationships and give a more in-depth understanding of students’ experiences. Also, a mixed-methods study allows the researcher to better understand a complex problem by collecting and integrating multiple sources of data, which helps utilize the strengths and minimize the weaknesses of each individual approach, adding to the quality of the study (Creamer 2016, Johnson & Onwuegbuzie 2004). The quantitative data included student survey responses and course grades, and the qualitative data included semi-structured interviews and classroom observations.

Mixed-methods quality considerations were guided by the legitimation framework by Onwuegbuzie and Johnson (2006). This includes components such as sample integration, which concerns the extent to which the quantitative and qualitative sampling designs result in quality meta-inferences, inside-outside legitimation, which refers to how well the researcher incorporates the insider (calculus students’) view and their own (observer’s) view for understanding the phenomenon, weakness minimization, which concerns the extent to which the weaknesses from one approach is compensated by the strengths from the other approach, and sequential legitimation which concerns the possible effect that the ordering of the quantitative and qualitative phases have on the findings.

1.5 Recruitment and Data Collection

The data for this study were collected in the Fall 2018 semester, following the timeline below:
Figure 1.2 Data Collection Timeline

This work was conducted with approval from the Clemson University Institutional Review Board (IRB), IRB2017-398. All recruitment and data collection materials were approved by the IRB to ensure ethical guidelines for human subject research. At the beginning of the semester, I met with each instructor to explain my study, get their permission to observe their classes, and administer the survey to students during class. The first time that I attended each section, I introduced myself to the class and explained my role as a researcher.

The students completed a survey twice throughout the semester during the first ten minutes of class. The survey was administered through Qualtrics (Qualtrics, Provo, UT), and students could access it either using their computer or phone. Students read an informational letter and chose to either consent or opt out of the survey (see Appendix A for informed consent letter for survey).

Once students were selected for follow up interviews, they were sent an IRB approved recruitment email inviting them to participate in the interview (see Appendix B
for recruitment email). At the beginning of the interview, I went over the logistics of the interview with each student, and they read an informed consent letter, explaining their role in the research study (see Appendix C for informed consent letter for the interviews).

1.6 Positionality Statement

According to Merriam, “because the primary instrument in qualitative research is human, all observations and analyses are filtered through that human being’s worldview, values, and perspective” (Merriam 2001, pg. 22). Thus, I would like to share my background and experiences that are relevant to studying calculus students that impact my interpretation of the data. I have held various roles related to the teaching and learning of mathematics as a student, tutor, graduate teaching assistant, and faculty member. While working on my bachelor’s degree, I worked as a tutor in our university math lab and developed a passion for helping students learn. This experience led me to decide to pursue a graduate degree in mathematics, with the ultimate goal of being an instructor for undergraduate math and statistics courses.

While teaching introductory math classes as a master’s student, I began to question what instructional practices were influencing my students’ motivation and engagement in the course. I wanted to gain a deeper understanding of student learning, best practices in STEM education, and current research in the field, so I decided to pursue a Ph.D. in STEM education research. My goals throughout my doctoral journey and this research project were to better understand the factors related to student success in calculus, specifically from the student perspective. Thus throughout the process of collecting and analyzing the data for this study, I bracketed (i.e., suspended) my
viewpoints from the instructor perspective to allow the students’ perceptions and experiences to be heard.

Findings from this study will help enhance knowledge about the factors contributing to student success in introductory college calculus. It is my hope that the results from this work will provide mathematics faculty with guidance on how to structure their courses in a way that is optimal for student motivation in order to empower them to succeed.
Chapter 2

Motivation: Impact of Course Policy Changes on Calculus I DFW Rates

This paper was originally published in the Journal of STEM Education: Innovations and Research in 2018.

The following modifications were made to include the article in this dissertation: 1) tables and figures were renumbered, 2) all references were moved to the full list at the end of the document, 3) acronyms were defined.


2.1 Abstract

This paper examines the impact of departmental policy changes on the trend in DFW proportions for introductory calculus at a large research university, where DFW denotes the proportion of students receiving a grade of D, F, or withdrawing from the course. We defined three distinct policy periods: Traditional (2002-2005), Active Learning (SCALE-UP) (2006-2013), and Return to Traditional (2014-2016). Regression analysis showed DFW proportions were increasing during the Traditional period, significantly decreased after the switch to SCALE-UP, remained fairly consistent during the SCALE-UP period, and then significantly increased during Return to Traditional. Individual trends for D, F, and W proportions were also analyzed. The two policy changes had the greatest influence on the trend in F and W proportions. Potential factors
that could influence a student to withdraw from the course were examined. Students who withdrew had midterm averages similar to students who failed the course during the SCALE-UP period, but their averages were significantly lower than the F students during the Return to Traditional period.

2.2 Introduction

The United States is in great need of more STEM graduates entering the workforce in order to sustain our nation’s global competitiveness. The President’s Council of Advisors on Science and Technology (PCAST) published the report Engage to Excel in 2012, which calls for one million more STEM professionals over the next decade (Olson et al. 2012). In order to achieve this goal, universities would need to increase STEM graduates by 34% annually. They suggest focusing on students in the first two years of college, since research has shown this time to be most critical to retaining STEM majors.

Student success in introductory calculus is imperative to obtaining a degree in any STEM field. During their first year, most STEM majors will enroll in Calculus I and II, which have been shown to be gatekeeper or barrier courses for engineering majors (Moore 2005, Suresh 2006). Barrier courses typically have the highest rate of failures or withdrawals at a university, and students who aren’t successful in these courses tend to switch majors to one that doesn’t require the barrier course (Moore 2005, Suresh 2006). Bressoud (2013) particularly emphasizes the importance of Calculus I for STEM retention:
Each fall, approximately 300,000 college or university students, most of them in their first post-secondary year, take this course. This course is famously perceived to be a filter, discouraging all but the very strongest students from pursuing a career in science or engineering. (p.685)

In addition to being a gatekeeper course, research shows that Calculus I “lowers students’ confidence, enjoyment of mathematics, and desire to continue in a field that requires further mathematics,” all having a negative impact on retaining STEM majors (Bressoud 2015). Therefore, in order to graduate more STEM professionals, we must start with examining the factors contributing to student success in Calculus I.

The impetus for this study was the university’s concern with a recent increase in DFW proportions for introductory calculus I (MATH 1060). Two major departmental policy changes for MATH 1060 took place in 2006 and then again in 2014 that impacted the trend in DFW rates. To better understand the implications of these policy changes, we decided to create a dataset of student grades spanning 2002-2016. These changes were a combination of instructional method, addition of new material, textbook and online homework software, testing format, placement policies, and passing conditions for the course. In order to study the effect of these changes on DFW proportions, we chose to focus solely on introductory calculus I courses (MATH 1060) taken in the fall semester. MATH 1060 is usually the first math course STEM majors take at the university. Thus, these students are typically around the same age and haven’t transferred pre-requisite course credit from another institution. Also, the fall semester for MATH 1060 is the traditional “on-track” semester for the course and the time most freshmen take calculus.
The spring semester adds many complexities such as students re-taking the course or students who started in a pre-calculus course (MATH 1050).

2.3 Summary of Changes

We defined three distinct periods that coincide with when the departmental policy changes were implemented. These periods are Traditional Methods (2002-2005), SCALE-UP (2006-2013), and Return to Traditional (2014-2016), which are defined below.

**Traditional Methods (2002-2005)**

The pedagogical approach used during this time was exactly what the section title suggests, “traditional lecture”. This specifically involved the components described in Table 2.1 below.

<table>
<thead>
<tr>
<th>Textbook</th>
<th>Homework</th>
<th>Exam Format</th>
<th>Grading Policy</th>
</tr>
</thead>
</table>

The homework during this period was not completed online, but consisted of daily assignments such as short quizzes, assigned problems, short writing assignments, problem presentations, or projects. Attendance in class was mandatory, with three percent of the final course average being dedicated to class attendance. The number of points a student was awarded for this category depended on the number of unexcused absences
they acquired: 0-1 (3 points), 2-4 (2 points), 5-6 (1 point), and greater than 6 unexcused absences resulted in 0 points. The first exam included a pre-calculus basic skills portion that was worth 25% of the overall test score. The final exam consisted of a calculator and a non-calculator portion. Once students turned in the first part of the exam, they were allowed to use a calculator to complete the second part. There were no additional passing conditions to the grading policy stated above.

**SCALE-UP (2006-2013)**

A new instructional method for MATH 1060 was first implemented in Fall 2006 called SCALE-UP (student centered activities for large enrollment undergraduate programs). The SCALE-UP approach supports student collaboration and active learning by minimizing lecture time and focusing on hands-on problem solving in the classroom. Active learning means that students are engaged in the learning process, rather than passively receiving information from a traditional lecture (Prince 2004). SCALE-UP classrooms usually consist of around 45 students with one instructor and one teaching assistant per room. Students sit at large round tables with three groups of three students each per table. This format encourages collaboration and helps develop a community of learners (Benson et al. 2008). Lectures are kept to less than 20 minutes, and students spend the remainder of class time working in groups on learning activities, which incorporate problems that apply the new concepts just presented. The instructor and TA guide group discussions and assist students in answering their own questions by having students explain their thinking, rather than just providing them with the correct answer.
This active learning environment has been shown to increase students’ conceptual understanding and support successful problem solving skills (Beichner et al. 2007).

Prior to the implementation of the SCALE-UP model in Fall 2006, all instructors were required to take part in a training workshop the week before the semester started. This workshop consisted of mock lessons that demonstrated both the content of the course as well as the new pedagogical approach. The instructors participated in the learning activity portion of the example lessons and discussed details about how to best assess the group work. Pertinent literature about the SCALE-UP model was also presented and discussed among the instructors during the training workshop.

Table 2.2. Overview of SCALE-UP period course policies

<table>
<thead>
<tr>
<th>Textbook</th>
<th>Homework</th>
<th>Exam Format</th>
<th>Grading Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2006-2009) <em>University Calculus Part One</em> (Hass, Weir, Thomas 2006)</td>
<td><em>MyMathLab</em> (Pearson)</td>
<td>50% Multiple choice</td>
<td>Three exams- 20% each Final exam- 20% Homework-10% Learning activities-10%</td>
</tr>
<tr>
<td>(2010-2013) <em>Calculus</em> (Briggs and Cochran 2010)</td>
<td>MyMathLab (Pearson)</td>
<td>50% Multiple choice</td>
<td>Three exams- 20% each Final exam- 20% Homework-10% Learning activities-10%</td>
</tr>
</tbody>
</table>

From Fall 2006- Fall 2013, this instructional method was coupled with closely coordinated courses sharing common exams, course material, online homework, and grading policies with the goal of reducing variability among sections of MATH 1060. The online homework software *MyMathLab* can include original content by instructors based on common student mistakes. Fisher and Lipson (1986) found that “pedagogical methods that systematically address common student errors produce significant gains in
student learning.” In addition to the grading policy above (Table 2), the passing conditions for the course stated students must pass the final exam or have a final passing average on the tests and final exam to receive a passing grade in the course. Also during this period, the placement policy emphasized careful class assignment based on students’ placement test score.

**Return to Traditional (2014-2016)**

In Fall 2014, another major departmental policy change for MATH 1060 took place. The instructional method changed from SCALE-UP to being determined by each individual instructor, with the majority of instructors returning to using traditional lecture. During this period, approximately 40% of instructors continued using the SCALE-UP model in Fall 2014 and only around 30% used SCALE-UP in Fall 2015.

Table 2.3. Overview of Return to Traditional course policies

<table>
<thead>
<tr>
<th>Textbook</th>
<th>Homework</th>
<th>Exam Format</th>
<th>Grading Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>ALEKS</em> (McGraw-Hill Education)</td>
<td></td>
<td>Homework-10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Learning activities-20%</td>
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<td></td>
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<td>Final exam-25%</td>
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<td></td>
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<td>(2015) Three exams-20% each</td>
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<td>Learning activities- 10%</td>
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<td>Final exam- 30%</td>
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<td>(2016) Three exams-20% each</td>
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<td>Learning activities- 10%</td>
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<td>Homework- 10%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Final exam- 20%</td>
</tr>
</tbody>
</table>

25
The homework software changed to WebAssign along with ALEKS (Assessment and LEarning in Knowledge Spaces), an online pre-calculus review, and the original content with common student mistakes was no longer available to students with this new software. The previous passing conditions were removed in 2014 with the added condition that an ALEKS score of less than 85 would result in lowering a student’s final course grade by one full letter grade. In Fall 2016, the passing condition of at least a 60% exam average or final exam score to pass the course was reinstated. New material was also added to the course during this period. Topics included delta-epsilon, Newton’s method, hyperbolic trig functions, proof by induction, and graphing functions with calculators.

Another major change in the placement policy occurred during the Return to Traditional period. Mathematics faculty developed the previous placement exam, which consisted of 50 multiple-choice questions and was scored on a scale from 1-6. The first half of the exam was an algebra skills test, and students were required to pass this section in order to receive a score of 4, 5, or 6 on the placement exam. Students could only take this exam one time but were given the opportunity to take the Algebra Exemption Test (AET) on the first night of classes if they were not satisfied with their placement exam score. A pass on the AET was equivalent to a placement exam score of 3. Along with the placement exam, students were required to take a basic skills test (BST) on the first day of the course. If a student scored a 3 or 4 on the placement exam, they were required to earn a sufficient BST score to be able to stay in the class. The new placement exam is administered to students through the ALEKS software. Students are given four attempts
on the new placement exam and must score an 80 or higher to be placed in the course. The BST is still given but is now only used for advisement purposes.

2.4 Research Questions

The major policy changes and the varying DFW proportions in MATH 1060 led to the following research questions for this study:

1) What is the actual trend in mean DFW proportions over time?
2) Are there significant change points in the DFW proportion trend associated with department policies being implemented or changed?
3) Are trends and change points similar for D, F, and W proportions?
4) What factors might influence students to withdraw from the course?

2.5 Results

In order to get a better picture of the trends in grades during the entire span of the study, we first developed four bar charts. Figure 1 is the total enrollment and Figures 2-4 show the number of D’s, F’s, and W’s respectively. We began to see trends in the numbers of D, F, and W grades associated with our three study periods. We noticed grades were changing consistently with our periods, but obvious from Figure 2.1, the total enrollment was also changing. Therefore, we decided to re-express Figures 2.2-2.4 in proportions of D, F, and W grades.
Figure 2.1. Total Enrollment for Fall MATH 1060

Figure 2.2. Number of D’s for Fall MATH 1060
Figure 2.3. Number of F’s for Fall MATH 1060

Figure 2.4. Number of W’s for Fall MATH 1060
The first graph (Figure 2.5) was used to determine the changes in overall DFW proportion versus year. Linear trend lines were fit within each period. Recall the three periods are Traditional Methods (2002-2005), SCALE-UP (2006-2013), and Return to Traditional (2014-2016). Figures 2.6, 2.7, and 2.8 are similar to Figure 2.5 except that the figures show the D, F, and W proportions respectively.

Figure 2.5. Total DFW Proportion for MATH 1060
Figure 2.6. D Proportion for MATH 1060

Figure 2.7. F Proportion for MATH 1060
In Figure 2.5, the overall DFW proportion slope and mean appears to change between Traditional Methods and SCALE-UP, and then change again between SCALE-UP and Return to Traditional. Figure 2.6 shows that the mean D proportion decreases from the Traditional Methods to SCALE-UP, but the change in the mean D proportion between SCALE-UP and Return to Traditional is not as dramatic. Figure 2.7 shows that the mean F proportion decreases slightly during the change from the Traditional Methods to SCALE-UP, continues decreasing during SCALE-UP, and then increases in the Return to Traditional period. Figure 2.8 shows that the mean W proportion decreases during the change from Traditional Methods to SCALE-UP, however the slope in W proportions slightly increases during the SCALE-UP period. The mean W proportion increases...
during the Return to Traditional Period, but the slope does not change much from the SCALE-UP period.

In addition to the descriptive analysis of the graphs, formal regression analysis was used to statistically compare slopes and means at the points where policies changed. A statistical model was developed for each grade proportion and the overall DFW proportion that included terms for year, period, and the year by period interaction. Assumptions concerning distributions, variances, and influential data points were also checked. The model was estimated and then F-tests of terms in the model were used to address the specific questions about the trend in means and slopes. This analysis revealed that slopes for Traditional Methods and SCALE-UP are significantly different (p=0.0273). The mean DFW proportion for Traditional Methods is significantly different than the mean proportion for SCALE-UP in 2006 (p <0.0001) and 2007 (p < 0.0001), with the estimate of the difference in means being 26.14%. Slopes for Return to Traditional and SCALE-UP are not significantly different (p=0.6336). However, the mean DFW proportion for Return to Traditional is significantly different than mean proportion for SCALE-UP in 2014 (p=0.0024) and 2015 (p=0.0008). The estimated difference in mean proportions is 12.15%. Overall, DFW proportions were rapidly increasing before the SCALE-UP period and drastically decreased after the policy changes made in Fall 2006. The DFW proportions remained fairly consistent during this period, and then significantly increased after the second round of policy changes that took place in Fall 2014.
Next, the total DFW proportions were separated into D’s, F’s, and W’s, and we analyzed the trends for each individual proportion. Throughout the literature regarding student success, these proportions are consistently reported together, and the individual proportions for each grade are not usually considered. The problem with introductory calculus is commonly indicated to be a high DFW proportion or a high rate of failures and withdrawals (Edge and Friedberg 1984, Suresh 2006, Benson et al. 2010, Pyzdrowski et al. 2012). Bressoud (2013) states “the grades DFW are grouped because they are all indicators that the students were not prepared to continue to any course with Calculus I as a prerequisite” (p.694). While this is certainly true, it is also important to consider the proportions of D’s, F’s, and W’s separately since different factors could lead students to withdraw rather than receive a D or F in the course.

First, we looked at the proportions of D’s. Slopes for the yearly changes in D proportions for Traditional Methods and SCALE-UP are not significantly different (p=0.0757). The mean D proportion for Traditional Methods is significantly different than mean D proportion for SCALE-UP in 2006 (p=0.0001) and 2007 (p=0.0001). The estimate of the difference in mean D proportions is 13.72%. Slopes for Return to Traditional and SCALE-UP are not significantly different (p=0.1361). The mean D proportion was slightly higher (p=0.0512) immediately after Return to Traditional, but by 2015 was not different than SCALE-UP (p=0.1968). Overall, the first round of policy changes made in Fall 2006 had a positive impact on reducing the proportion of D’s, while no significant changes were seen after the Fall 2014 policy changes.
Next, we analyzed the trend in the proportion of F’s for the course. Slopes for the yearly changes in F proportions for Traditional Methods and SCALE-UP are significantly different (p=0.0023). The mean F proportion for Traditional Methods is significantly different than the mean proportion for SCALE-UP in 2006 (p=0.0089) and 2007 (p=0.0041). The estimate for the difference in mean F proportions is 6.36%. Slopes for Return to Traditional and SCALE-UP are significantly different (p=0.0413). The mean F proportion for Return to Traditional is significantly different than the mean proportion for SCALE-UP in 2014 (p=0.0348) and 2015 (p=0.0019). The estimate of the difference in mean F proportions is 6.50%.

Finally we examined withdrawal proportions. Slopes for Traditional Methods and SCALE-UP are not significantly different (p=0.2755). The mean W proportion for Traditional Methods is significantly different than the mean proportion for SCALE-UP in 2006 (p=0.0424), but not in 2007 (p=0.1489). The estimate for the difference in mean W proportions is 6.06%. Slopes for Return to Traditional and SCALE-UP are not significantly different (p=0.9415). The mean W proportion for Return to Traditional was slightly different than the mean proportion for SCALE-UP in 2014 (p=0.0821), and also in 2015 (p=0.0542). The estimate of the difference in mean W proportions is 4.50%.

Overall, the two policy changes appeared to be more associated with F and W proportions than with D proportions. This led us to further investigate failures and withdrawals. We proceeded by examining factors that could impact a student’s decision to withdraw from the course. A search of the literature showed very few articles regarding individual course withdrawals, with most focusing on college retention rates.
There is a large amount of research concerning overall withdraw from higher education, but the literature on individual course withdrawal is less developed (Michalski 2011). According to Dunwoody and Frank (1995), course withdrawal rates have been ignored, and there is no information in the literature regarding how course withdrawal impacts the chance of a student completing their degree. Also, Hall (2003) found that “very little research has been conducted and published regarding the reasons a student withdraws from a course,” even though course withdrawal negatively impacts students’ progress towards graduation (p. 2). They further state that “this will be particularly true if the course is the first in a sequence of required courses,” which is certainly the case for introductory calculus for STEM majors (Hall et al. 2003, p. 2). Thus, studying reasons why students withdraw from this course is crucial to ensuring more STEM students successfully complete their degree.

Despite the lack of information in the literature regarding students’ reasoning behind course withdrawal, two studies have been conducted that shed some light on the issue. Hall (2003) found that the main reason students withdrew from a class was that they were doing poorly in the course. Also, Dunwoody and Frank (1995) identified “I was not happy with my grade” as the top reason students indicated for withdrawing. We hypothesized that many withdrawing students were actually achieving a B, C, or D letter grade, but wanted or needed a higher grade (A, B, or C, respectively) and chose to withdraw instead of achieving the lower grade. In order to investigate this, we looked at the mean of students’ midterm averages for each of the final letter grades (Figure 2.9). This was done for two periods, SCALE-UP and Return to Traditional. If our hypothesis
was correct, we would expect the mean of the midterm averages for W students to be somewhat similar to the B, C, and D final letter grades.

![Mean Midterm Average vs. University Letter Grade](image)

**Figure 2.9. Mean Midterm Average vs. Final Letter Grade**

From Figure 2.9, we can see that our hypothesis was not correct. To formally test our hypothesis, first we used ANOVA to determine that the mean midterm averages differed based on final letter grade for both 2013 ($p < 0.0001$) and 2014 ($p < 0.0001$). Fisher’s LSD was then used to compare the mean midterm average for W students to all other final grades. The mean of the midterm averages for the W students was significantly lower than the B, C, and D final grades ($p$-values $< 0.0001$), and in fact looks most similar to the midterm average of students who received an F for their final grade in the course. Also, the mean midterm averages for F and W students were not
significantly different in Fall 2013. After the policy changes made in Fall 2014, the mean midterm average for W students was significantly lower than B, C, D, and F students (p-values < 0.0001). Therefore, students were making the correct decision to withdraw since they were indeed failing the class, not just unhappy with a low but passing grade like we hypothesized. Additionally, the mean midterm average for W students is significantly lower (p <0.0001) for the Return to Traditional period (mean=19.98) than for the prior SCALE-UP period (mean=43.55). Another important observation is that the mean midterm averages for the A, B, and C grades remained fairly stable after the policy changes. Thus, the change in instructional approach from SCALE-UP back to traditional methods has specifically impacted the struggling students and resulted in even lower midterm averages for students who chose to withdraw.

2.6 Conclusion

This research was motivated by a recent increase in DFW proportions for introductory college calculus. In order to gain insight into factors contributing to this increase, the relationship of two major departmental policy changes to the trend in DFW proportions were explored. Individual D, F, and W trends were also studied. By analyzing the trend in DFW proportions from Fall 2002-Fall 2015, we found that the two policy were strongly related to the overall DFW rate, with students being the most successful (in terms of the DFW proportions being lower) during the SCALE-UP period of instruction. Another important finding was that the policy changes for MATH 1060 had the greatest influence on the course’s F and W proportions.
After examining students’ midterm averages to further understand the F and W proportions, we discovered that the students who withdrew had averages similar to students who failed the course during the SCALE-UP period. However, the midterm averages for W students were significantly lower than the F students when the math department’s policy returned to using traditional pedagogical methods, giving more evidence to support the positive influence of SCALE-UP on reducing DFW proportions.

2.7 Limitations

It is important to emphasize that the possible cause of the change in DFW rates were the policy changes in general. It is an unfortunate shortcoming of the data available for this study that a plethora of factors were all changed simultaneously. Therefore, it is impossible to attribute the change in DFW rates to any specific factors or even order the factors as to their contribution to the changes that occurred. An important addition to this study would be to identify a university where course policies were changed with the specific purpose of conducting a statistical factorial study suitable for pinpointing specific factors involved in DFW rate changes.

Another important note is that DFW trends were not separated across demographic subsets of students, as defined by gender, ethnicity, and major combinations. In addition, the different demographic groups of students were not equally represented in the course. How the DFW trends change due to policies, separated by demographic subsets, will be explored in future work.
Chapter 3

Exploring the Relationship Between Course Structures and Student Motivation in Introductory College Calculus

This paper was presented at the 2019 American Society for Engineering Education (ASEE) conference in Tampa, FL and is included in the conference proceedings. The following modifications were made to include the article in this dissertation: 1) tables were renumbered, 2) discussion of the reliability of the survey instrument was added, 3) additional research questions with corresponding analyses were added, 4) conclusion section was modified based on these additional analyses, 5) all references were moved to the full list at the end of the document.


3.1 Abstract

The Mathematical Association of America (MAA) national study of Characteristics of Successful Programs in College Calculus revealed that introductory calculus still occupies a gatekeeper role for STEM majors across the country. Even if students persist through Calculus I, they leave the class with a diminished confidence and enjoyment of mathematics and a decreased desire to continue pursuing further mathematics. Thus, the goal of this research study was to provide a better understanding
of the relationship between learning environments and student motivation in introductory college calculus. Results of this work will help guide mathematics faculty and administrators to create environments that are most conducive to fostering students’ motivation, thus supporting their academic achievement in calculus.

The theoretical framework of self-determination theory (SDT) was used to guide this study. SDT is a macro-theory of motivation and has been widely used to study the social factors of an environment under which people thrive. According to SDT, three basic psychological needs are essential to fostering a student’s motivation and engagement: competence, autonomy, and relatedness. Competence refers to students feeling confident and effective in the classroom, autonomy means they have a sense of agency and authority, and relatedness incorporates students’ need to feel a sense of belonging in the classroom. Only when students’ basic psychological needs are supported by the classroom structure can they internalize their motivation to learn.

This paper will report a piece of a larger sequential explanatory mixed-methods design that investigated the interaction of course structures, students’ basic psychological needs satisfaction, and motivation. Three different course types of Calculus I were sampled at a large research university, which included traditional methods, hybrid online, and a large-enrollment active learning classroom. The Basic Psychological Needs Scale (BPNS) and the Situational Motivation Scale (SIMS) were administered to students in the three course types. This quantitative phase involved analyzing survey data from all students in the selected classes to determine if students’ perceptions of their competence, autonomy, and relatedness and motivation types differed between the course structures.
Analyses revealed that students’ perceptions of their competence, autonomy, relatedness and autonomous motivation significantly differed between the three course types, with the hybrid online class having significantly lower mean scores than the other two course types. Implications for mathematics faculty will be discussed.

3.2 Introduction/Background

The Mathematical Association of America (MAA) national study of Characteristics of Successful Programs in College Calculus revealed that introductory calculus still occupies a gatekeeper role for STEM majors across the country. Bressoud (2013) illustrates this issue with introductory calculus by stating, “this course is famously perceived to be a filter, discouraging all but the very strongest students from pursuing a career in science or engineering”. Gatekeeper courses typically have the highest rate of failures or withdrawals at a university, and students who aren’t successful in these courses tend to switch out of a STEM major (Moore 2005, Suresh 2006). Even if students persist through Calculus I, they leave the class with a diminished confidence and enjoyment of mathematics and a decreased desire to continue pursuing further mathematics. Students at research universities, which are the primary source of our future scientists and engineers, are showing the greatest losses in these factors (Bressoud et al. 2015). This presents a critical issue as our nation is in great need of more STEM graduates entering the workforce (Olson et al. 2012).

These findings become even more discouraging when we take a closer look at the positive characteristics of students entering university calculus. Students have strong academic backgrounds coming into Calculus I, with an average high school math GPA of
Additionally, 70% of students have taken calculus in high school prior to enrolling at the university level (Bressoud et al. 2015). Recognizing that students are entering calculus with the preparation to succeed, more attention needs to be paid to the learning environment provided to these students; specifically, how pedagogical choices are impacting students’ motivation and performance in calculus. Calculus I course structures with common content and exams, but with differing levels of active learning, were examined in this study. The framework of self-determination theory (SDT) was used to investigate the social conditions in different course structures that either facilitate or forestall the innate interest and ambition for learning that calculus students possess (Ryan & Deci 2000).

3.3 Theoretical Framework

The framework of self-determination theory (SDT) was used to guide this study. Self-determination theory is a macro-theory of human motivation that was developed by psychologists Deci and Ryan. Ryan and Deci (2000) state, “human beings can be proactive and engaged or, alternatively, passive and alienated, largely as a function of the social conditions in which they develop and function” (pg. 68). They stress the importance of doing research on the design of social environments in order to determine the best conditions for optimizing people’s development, performance, and well-being, thus making this an important framework to study classroom structure. As such, SDT has been widely applied in the educational domain. According to SDT, three needs are essential to fostering a student’s motivation and engagement: competence, autonomy, and relatedness. Competence refers to students feeling confident and effective in the
classroom. Autonomy refers to students’ sense of agency and authority. Finally, relatedness incorporates students’ need to feel a sense of belonging in the classroom.

Self-determination theory also describes motivation in terms of autonomous versus controlled regulation. These different types of regulations are defined by the extent to which the student has internalized a certain behavior. Controlled regulations include amotivation, where the student completely resists and does not value the classroom activities, external regulation, meaning a student participates in order to get a good grade on exam or avoid looking incompetent, and introjected regulation, in which a student engages in classroom activity in order to avoid shame or feel worthy. On the other side of the spectrum is autonomous regulation, which includes identified regulation, integrated regulation, and intrinsic motivation. Behaviors that are more autonomously regulated have been integrated into a student’s sense of self (Black & Deci 2000).

Identified regulation means that the activity is accepted as personally important, such as students studying calculus in order to progress in their major. Integrated regulation is the most autonomous form of extrinsic motivation; as such it is very similar to intrinsic motivation. A student experiencing integrated regulation has fully incorporated a behavior into other aspects of themselves, thus assimilated it into their identity (Deci et al. 1991). For example, a student might study calculus in order to become an engineer and be able to help others, “which is consistent with her abiding values and interests” (Niemiec & Ryan 2009).

SDT posits that extrinsically motivated behaviors, such as taking a calculus class, can only become autonomously regulated, meaning that the behavior has been integrated
into their sense of self, if the social context promotes feelings of competence, autonomy, and relatedness. In other words, students’ individual motivation is constrained by the norms of the classroom (Goldin et al. 2016). When students’ basic psychological needs are supported by the classroom structure, they are more likely to internalize their motivation to learn (Niemiec & Ryan 2009). Many prior studies in education, ranging from elementary school to college, have shown the importance of promoting autonomous regulation in the classroom (Deci et al. 1991). In general, more autonomous forms of motivation have been linked to increased interest, excitement, and confidence. This has been shown to lead to higher performance and persistence, even among students with the same level of self-efficacy (Ryan & Deci 2000).

3.4 Context

To study the relationship between course structures and student motivation, we sampled three different course types of Calculus I in the Fall 2018 semester: large active learning, hybrid online, and traditional methods. Calculus I at our university is a coordinated course, with every section covering the same material, using the same online homework, and taking the same exams. We sampled two sections of each course type, with the same instructor teaching both sections of a course type, with a total sample size of 340 students.

The large active-learning course was held in a large computer lab. There were around 90 students in each section, and students attended class four days a week. This course structure involved a mixture of lecture and group activities. Each student had a
computer and was able to follow along with the instructor’s slides during the lecture portion of the class. Two graduate teaching assistants, the instructor, and an undergraduate TA assisted students and answered questions during the active learning part of the class.

The next course type was hybrid online, which consisted of around 40 students in each class. These hybrid sections involved students watching online lectures and attending class face-to-face two days a week. One day was used for quizzes over the content covered that week, and the other day involved students working in groups on a learning activity. The quizzes and group activities took place during the first half of class, and the TA worked example problems during the second half of class. This classroom was set up with round tables, with a projector screen at each end of the room.

The last course type in this study was a traditional methods class. Like the hybrid class, students sat together at round tables, with around 45 students in each section. The instructor lectured throughout the class period with an interactive approach, stopping to ask students questions or get their ideas about how to solve a problem. There were no consistent group activities in this class like the other two course types, and this course type did not have any TAs in the classroom.

3.5 Methods

The Basic Psychological Needs Satisfaction Scale (BPNS) and the Situational Motivation Scale (SIMS) were administered twice to all students in the six selected sections, once at the beginning of the semester and once at the end. The BPNS was developed by Deci and Ryan (2000) and contains 21 items that measure participants’
perceptions of their autonomy (7 items), competence (6 items), and relatedness (8 items) as defined by self-determination theory. This scale has been adapted for use in an undergraduate classroom, and prior studies have shown internal reliabilities ranging from $\alpha=0.77$ to 0.86 for the three subscales (Filak & Sheldon 2003, Levesque-Bristol et al. 2010, Hsu, Wang, & Levesque-Bristol 2019).

The Situational Motivation Scale (SIMS) was developed by Guay et al. (2000) and contains 18 items designed to measure the six types of motivation proposed by self-determination theory. This scale has been previously validated with college students and was shown to be reliable with internal consistencies ranging from $\alpha=0.77$ to 0.95 for the six subscales of intrinsic, integration, identification, introjection, extrinsic, and amotivation (Guay et al. 2000, Levesque-Bristol et al. 2010, Levesque-Bristol et al. 2011, Hsu, Wang, & Levesque-Bristol 2019). Additionally, the literature suggested that these six subscales formed two meaningful constructs: autonomous motivation (intrinsic, integration, identification) and controlled motivation (introjection, extrinsic, amotivation). Therefore, those two constructs of the SIMS were used in this study.

To ensure these theoretical constructs existed for our population of students in this study, a combination of factor analysis and pairwise correlations among the items was used to assess the reliability of the survey instrument. These analyses revealed that the three theoretical constructs underlying the BPNS (autonomy, competence, and relatedness) and two theoretical constructs underlying the SIMS (autonomous and controlled motivation) appeared to exist for this population of students.
In addition to the BPNS and the SIMS, the survey included items to determine if students have previously taken calculus, and student demographic data such as gender and ethnicity was also collected.

The sample size and response rates for each course type are given below:

Table 3.1. Sample Size and Response Rate

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Sample Size</th>
<th>Pre Survey</th>
<th>Post Survey</th>
<th>Post Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large active learning</td>
<td>N=176</td>
<td>N=169</td>
<td>N=140</td>
<td>79.5%</td>
</tr>
<tr>
<td>Hybrid online</td>
<td>N=75</td>
<td>N=70</td>
<td>N=51</td>
<td>68%</td>
</tr>
<tr>
<td>Traditional methods</td>
<td>N=89</td>
<td>N=84</td>
<td>N=59</td>
<td>66%</td>
</tr>
</tbody>
</table>

3.6 Results

The following analyses were conducted on students’ post survey scores.

RQ 1.1) What is the difference in student perceptions of their basic psychological needs satisfaction between the course structures?

A multivariate analysis of variance (MANOVA) model was developed to determine if students’ combined means of the BPNS components (competence, autonomy, and relatedness) differ based on course structure. The MANOVA allows for comparison of a multivariate mean response between groups (Rencher 2002). This model included terms for course structure (the treatment) and student demographic groups (the blocking factor). Use of a blocking factor allows for a comparison of course structures that is not masked by pre-existing differences among students based on the demographics.
The blocking factor was defined by students’ gender, ethnicity, and prior calculus experience.

Since the MANOVA model suggested course structure was significant \( (p < 0.0001) \), univariate ANOVA models were used to determine which of the individual components of the multivariate mean response in the BPNS differed between the course structures. Since the univariate ANOVA tests were significant for each BPNS component, all pairwise comparisons were conducted to determine which of the course types had significantly different autonomy, competence, and relatedness scores. For each BPNS component, the hybrid online course had significantly lower mean scores than the traditional and large active learning courses.

Table 3.2. BPNS by Course Type

<table>
<thead>
<tr>
<th>BPNS Component</th>
<th>ANOVA</th>
<th>Traditional</th>
<th>Active</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy</td>
<td>F 3.62</td>
<td>p-value 0.0284*</td>
<td>M 3.95</td>
<td>SE 0.12</td>
</tr>
<tr>
<td>Competence</td>
<td>F 9.63</td>
<td>p-value &lt;0.0001*</td>
<td>M 4.05</td>
<td>SE 0.15</td>
</tr>
<tr>
<td>Relatedness</td>
<td>F 6.77</td>
<td>p-value 0.0014*</td>
<td>M 4.98</td>
<td>SE 0.12</td>
</tr>
</tbody>
</table>

RQ 1.2) What is the difference in student motivational types between the course structures?

Next, the same process used for RQ 1.1 above was followed. Since the MANOVA was significant \( (p=0.0055) \), univariate ANOVA models were developed for each factor. The ANOVA for autonomous motivation was significant; therefore, all pairwise comparisons between the course types were conducted. Results showed that the
hybrid online course had a lower mean autonomous motivation score than the traditional and large active learning courses.

Table 3.3. SIMS by Course Type

<table>
<thead>
<tr>
<th>SIMS Component</th>
<th>ANOVA</th>
<th>Traditional</th>
<th>Active</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Autonomous Motivation</td>
<td>7.45</td>
<td>4.19</td>
<td>0.16</td>
<td>4.37</td>
</tr>
<tr>
<td>Controlled Motivation</td>
<td>0.69</td>
<td>4.00</td>
<td>0.12</td>
<td>3.95</td>
</tr>
</tbody>
</table>

While the first two research questions concerned differences in the BPNS and SIMS among the three course types, the next research questions concerned changes in the BPNS and SIMS scores from the beginning to the end of the semester.

RQ 1.3) Do students’ perceptions of their basic psychological needs satisfaction change from the beginning to the end of the semester? Does this change differ based on course structure?

A repeated measures MANOVA model was developed to determine if students’ combined means of the three BPNS components differed from the beginning to the end of the semester. Since the MANOVA was significant (p=0.0312), subsequent univariate repeated measures ANOVA models were developed to determine which components in the BPNS changed from the beginning to the end of the semester. Results showed that students’ competence perceptions significantly decreased from the beginning to the end of the semester. We report only the overall change in autonomy, competence, and relatedness because the effect of course type and student demographics on these changes
were not significant. (the interaction terms between course structure and time (pre/post), and the blocking factor and time (pre/post) were not significant, meaning these changes were consistent.)

Table 3.4. BPNS by Time (Pre/Post)

<table>
<thead>
<tr>
<th>BPNS Component</th>
<th>ANOVA</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p-value</td>
</tr>
<tr>
<td>Autonomy</td>
<td>3.09</td>
<td>0.0794</td>
</tr>
<tr>
<td>Competence</td>
<td>8.62</td>
<td>0.0035*</td>
</tr>
<tr>
<td>Relatedness</td>
<td>0.33</td>
<td>0.5686</td>
</tr>
</tbody>
</table>

RQ 1.4) Do students’ motivational types change from the beginning to the end of the semester? Does this change differ based on course structure?

Similar to RQ 2.1, a repeated measures MANOVA model was developed to determine if students’ combined means of the SIMS components differed from the beginning to the end of the semester. Since the MANOVA was significant (p <0.0001), subsequent univariate repeated measures ANOVA models were developed next. Results showed that students had decreased autonomous motivation and increased controlled motivation from the beginning to the end of the semester. As before, we report only the overall change in autonomous and controlled motivation because the effect of course type and student demographics on these changes were not significant. (the interaction terms between course structure and time (pre/post), and the blocking factor and time (pre/post) were not significant, meaning these changes were consistent.)
Table 3.5. SIMS by Time (Pre/Post)

<table>
<thead>
<tr>
<th>SIMS Component</th>
<th>ANOVA</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p-value</td>
<td>M</td>
</tr>
<tr>
<td>Autonomous Motivation</td>
<td>27.35</td>
<td>&lt;0.0001*</td>
<td>4.62</td>
</tr>
<tr>
<td>Controlled Motivation</td>
<td>9.17</td>
<td>0.0026*</td>
<td>3.77</td>
</tr>
</tbody>
</table>

After testing for differences based on course type and changes from the beginning to the end of the semester, next we wanted to see if we could predict student performance in the class based on their BPNS and SIMS scores.

RQ 1.5/1.6) What is the relationship between students’ basic psychological needs satisfaction/motivation type and final grade in the course?

Multiple regression models were used in order to determine how the BPNS and SIMS components are related to final grades. The BPNS components (competence, autonomy, and relatedness) and the SIMS components (autonomous and controlled motivation) were used as predictors with final numeric grade as the response variable. Results showed that competence, autonomous motivation, and controlled motivation were all significant predictors of final course average, with competence and autonomous motivation being positively associated with final grade and controlled motivation being negatively associated with final grade. Once again, we report only one overall model for the relationship between course performance and BPNS components and one overall model for the relationship between course performance and SIMS components because the effect of course type and student demographics on these relationships were not
significant (the interaction terms of course structure*BPNS and blocking factor*BPNS were not significant; and the interaction terms of course structure*SIMS and blocking factor*SIMS were not significant).

Table 3.6. BPNS and Final Grade

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>Autonomy</td>
<td>-0.22</td>
<td>1.45</td>
</tr>
<tr>
<td>Competence</td>
<td>6.19</td>
<td>1.16</td>
</tr>
<tr>
<td>Relatedness</td>
<td>1.25</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Table 3.7. SIMS and Final Grade

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>Autonomous Motivation</td>
<td>3.58</td>
<td>0.71</td>
</tr>
<tr>
<td>Controlled Motivation</td>
<td>- 4.51</td>
<td>0.98</td>
</tr>
</tbody>
</table>

3.7 Conclusions

Overall, students in the hybrid online course had significantly lower autonomy, competence, and relatedness perceptions, as well as lower autonomous motivation scores, compared to the traditional and large active learning courses, even when controlling for prior calculus experience, gender, and ethnicity. In all course types, students’ competence perceptions decreased throughout the semester, as well as their autonomous motivation scores, while their controlled motivation scores increased. When exploring if there was an association between course performance and the basic psychological needs components and motivational types, we found that competence and autonomous
motivation were positively associated with final grade, and controlled motivation was negatively associated with final grade.

In order to get a better idea of what aspects of each course structure could be contributing to these quantitative results, follow-up student interviews were conducted in the qualitative phase of this larger mixed-methods study. These findings are presented in Chapter 4 along with a discussion about implications for mathematics faculty.
Chapter 4

Towards creating motivationally supportive course structures for introductory calculus

This paper will be presented at the 2020 American Society for Engineering Education (ASEE) conference and will be published in the conference proceedings.

The following modifications were made to include the article in this dissertation: 1) tables were renumbered, 2) all references were moved to the full list at the end of the document, 3) format was changed from the conference requirements to an appropriate dissertation chapter.


4.1 Abstract

This paper reports the qualitative phase of a sequential explanatory mixed-methods study focused on exploring the relationship between course structures and student motivation in introductory college calculus. The theoretical framework of self-determination theory (SDT) guided this study, which defines three basic psychological needs that are essential to fostering students’ motivation: competence, autonomy, and relatedness. SDT also describes motivation along a continuum from autonomous to controlled forms of motivation. Prior work has revealed that more autonomous forms of
motivation have been linked to higher performance and persistence among students. We sampled three course types of Calculus I at a large research university (traditional lecture, large active learning, and hybrid online), with the goal of better understanding what aspects of each course structure are supporting students’ basic psychological needs.

Students in these three course types were given the The Basic Psychological Needs Scale (BPNS) and the Situational Motivation Scale (SIMS). Cluster analysis of the survey data revealed two groups of students: those with high competence, autonomy, and relatedness perceptions and high autonomous motivation and those with low competence, autonomy, and relatedness perceptions and high controlled motivation. We purposefully selected students based on the cluster analysis to participate in semi-structured interviews with two members of our research team. The qualitative analysis of our interview data revealed different components of each course type that are contributing to student’s perceptions of their competence, autonomy, and relatedness. Implications for mathematics faculty about how to make course structures more motivationally supportive for calculus students will be discussed.

4.2 Introduction

Calculus I serves as a gatekeeper course to STEM majors (Bressoud, Mesa, & Rasmussen 2015, Suresh 2006). In addition to having a high failure rate, students leave this course with a decreased confidence and enjoyment of mathematics, with students at research universities showing the greatest decrease in these aspects throughout the course (Bressoud et al. 2013). This poses a significant challenge since these universities are the main source of our future scientists and engineers, and our nation is in need of more
STEM majors entering the workforce in order to sustain our global competitiveness (Olsen 2012).

The Mathematical Association of America (MAA) national study of Characteristics of Successful Programs in College Calculus investigated this issue by looking at characteristics of introductory calculus courses that were impacting students’ attitudes and performance. Findings from this study showed that pedagogical factors had a significant relationship with student attitudes, and the authors suggested that use of student-centered pedagogies and active learning strategies was one important characteristic of successful calculus programs (Bressoud & Rasmussen 2015).

This nationwide issue of a high failure rate for introductory calculus has also been seen at our university in recent years. This challenge sparked a prior study (see Norton, Bridges, & High 2018) to investigate the impact of the mathematics department’s course policy changes on Calculus I DFW rates, where DFW denotes the proportion of students receiving a grade of D, F, or withdrawing from the course. One of these departmental policy changes included implementing a highly coordinated active learning instructional model in all Calculus I classes. Analysis of trends in student grade data revealed that DFW rates were significantly lower during the active learning period of instruction (Norton, Bridges, & High 2018). This result aligns with the MAA’s finding that the use of active learning pedagogies was associated with successful calculus programs. This paper will report the qualitative piece of a larger mixed-methods project designed to investigate this relationship further by studying students’ perceptions of Calculus I course
structures with varying levels of active learning. These course structures included a traditional lecture, hybrid online, and large active learning classroom.

4.3 Theoretical Framework

The lens of self-determination theory (SDT) was used to guide this study. SDT is a broad theory of human motivation developed by psychologists Deci and Ryan, and has been used widely to study the design of social environments, such as a classroom (Ryan & Deci 2000). SDT posits that three basic psychological needs are necessary to support a students’ motivation: competence, autonomy, and relatedness (Deci & Ryan 2000). Competence refers to students feeling confident and effective in the classroom. Autonomy means students have a sense of agency and authority. Relatedness involves students feeling connected with others and incorporates students’ need to feel a sense of belonging in the classroom (Niemiec & Ryan 2009).

SDT also describes motivation along a continuum from autonomous to controlled regulation. These regulations vary from low to high degrees of self-determination (Lavigne et al. 2007). Controlled regulations include amotivation, external regulation, and introjected regulation. On the other side of the spectrum is autonomous regulation, which includes identified regulation, integrated regulation, and intrinsic motivation. Integrated regulation is the most autonomous form of extrinsic motivation; therefore, it is very similar to intrinsic motivation.

Many educational studies have shown the importance of promoting autonomous regulation in the classroom (Deci et al. 1991, Ryan & Deci 2000, Black & Deci 2000, Lavigne et al. 2007). Overall, more autonomous forms of motivation have been
associated with increased interest, excitement, and confidence. This has been shown to lead to higher performance and persistence of students (Ryan & Deci 2000). According to Niemiec and Ryan (2009), “autonomous types of extrinsic motivation are associated with enhanced student learning” (pg. 139). Behaviors that are extrinsically motivated, such as taking a calculus class, can only become autonomously regulated if the social context promotes students’ perceptions of competence, autonomy, and relatedness. Overall, students are more likely to develop more autonomous forms of motivation when their basic psychological needs are supported by the classroom environment (Niemiec & Ryan 2009).

The need for autonomy can also be broken down into three separate types: organizational, procedural, and cognitive autonomy. Organizational autonomy refers to students being able to have input into the classroom procedures such as selecting due dates or choosing group members or seating assignments. Procedural autonomy support involves students having choice in the form of their work such as choosing the materials for a project. Cognitive autonomy refers to student ownership of their learning. This involves students having opportunities to think through the material on their own and discuss solutions with others (Stefanou et al. 2004). Stefanou et al. (2004) suggest that cognitive autonomy may be the most beneficial form of autonomy to promote in the classroom in order to support student motivation.
4.4 Research Question

What aspects of each Calculus I course structure (traditional lecture, hybrid online, and large active learning) are supporting students’ basic psychological needs?

4.5 Course Structures

To explore the what aspects of the course structures were related to student perceptions of their basic psychological needs, we sampled three different course types of Calculus I at a large research university in the southeastern U.S. These course structures are summarized below in Table 4.1. These were the available course structures for Calculus I at this university at the time of data collection. For each course type, we selected two sections of each, with the same instructor teaching both sections of a course type. Calculus I at this university is a coordinated course, so each course type shared common content, textbook, online homework, and exams.

Table 4.1 Summary of Course Structures

<table>
<thead>
<tr>
<th>Traditional Lecture</th>
<th>Large Active Learning</th>
<th>Hybrid Online</th>
</tr>
</thead>
<tbody>
<tr>
<td>~45 students per section</td>
<td>~90 students per section</td>
<td>~40 students per section</td>
</tr>
<tr>
<td>Classroom with round tables with 9 students</td>
<td>Large computer lab with seats in rows</td>
<td>Classroom with round tables with 9 students</td>
</tr>
<tr>
<td>4 days a week</td>
<td>4 days a week</td>
<td>Face-to-face 2 days a week</td>
</tr>
<tr>
<td>Lecture with an interactive approach, stopping to ask students questions and get their ideas about how to solve a problem.</td>
<td>Mix of lecture and group activities</td>
<td>Online recorded lectures</td>
</tr>
<tr>
<td>Instructor, graduate and undergrad TAs assisted students and answered questions during the active learning part of the class.</td>
<td>Quiz and TA working problems one day</td>
<td>Group activity and TA working problems the other day</td>
</tr>
</tbody>
</table>
4.6 Methods

In order to characterize the different course structures, I conducted classroom observations. Observations in qualitative research allow the researcher to have a “firsthand account of the situation under study” and “allows for a holistic interpretation of the phenomenon being investigated” (Merriam 2001, pg. 111). I utilized the observer as participant role while conducting the observations, which means the students were aware of my role as a researcher, but I did not take part in the classroom activities (Merriam 2001). I sat off to the side of the classroom and wore casual clothing in order to minimize my presence as much as possible.

I took fieldnotes that included descriptions of the physical setting of the classroom, interactions that occurred (instructor to student, and student to student), and the structure of the lesson. These observations add to the quality of the study by providing data triangulation with the participants’ descriptions of the course structures in their interviews (Patton 2002). In terms of the legitimation framework for mixed-methods research, the observations also add to the inside-outside validity of the study, which refers to “the extent to which the researcher accurately presents and appropriately utilizes the insider’s view and the observer’s views for purposes such as description and explanation” (Onwuegbuzie et al. 2011, pg. 1256). The observations allowed me to have a better understanding of how the students were describing the different course structures and the day-to-day activities that took place in the classrooms (i.e. the insider’s view).
Quality considerations for the qualitative phase of this study were informed by the Q³ Framework by Walther, Sochacka, and Kellam (2013). This framework includes the following aspects: **Theoretical and procedural validity** concerns the fit between theory and the social reality under investigation and what features of the research design improve that fit. **Communicative validity** refers to co-constructing meanings of participants’ social realities on their own terms. **Pragmatic validity** concerns the compatibility of the theoretical constructs with empirical reality. **Process reliability** refers to the mitigation of random influences on the research process. I will use the format by Anderson and Martin (2017) by connecting each methods decision I discuss to the quality consideration it addresses by putting the category in parentheses.

Since this study is part of a larger sequential explanatory mixed-methods design, we first conducted a quantitative phase to get a broad picture of students’ perceptions of their basic psychological needs satisfaction and motivational types in the different courses. We administered the Basic Psychological Needs Satisfaction Scale (BPNS) (Deci & Ryan 2000, Levesque-Bristol et al. 2010) and the Situational Motivation Scale (SIMS) (Guay et al. 2000) at the beginning and the end of the semester to all students in the selected classes.

In order to select participants for our interviews, cluster analysis was used to explore patterns in the data set by grouping students into homogenous clusters based on their survey responses. The objective of cluster analysis is to have students within each cluster be similar, while maximizing the variation between clusters (Rencher 2002). Since we didn’t have a predetermined idea of the number of clusters we were looking for,
we performed three commonly suggested methods: principal components, k-means, and hierarchical. Based on the characteristics of our dataset, it wasn’t clear which of these three methods was most appropriate. However, each method gave us the same result of two clusters. Therefore, we chose principal components for ease of interpretation and displaying the results (*communicative validity*).

The cluster analysis revealed two distinct groups of students within each course type as shown in Figures 4.1 and 4.2 below: 1) those with low competence, autonomy, relatedness and high controlled motivation (red) and 2) those with high competence, autonomy, relatedness and high autonomous motivation (green).

![Figure 4.1. Biplot of Cluster Analysis](image-url)
As seen in Figure 4.2, students with higher autonomy, competence, and relatedness perceptions tended to have higher autonomous motivation and lower controlled motivation scores. This relationship is consistent with self-determination theory literature, in that “contexts supportive of autonomy, competence, and relatedness were found to foster greater internalization and integration” (Ryan & Deci 2000, pg. 76). In other words, classroom contexts that support students’ autonomy, competence, and relatedness perceptions are more likely to foster autonomous forms of motivation.

Based on these results from the cluster analysis, specific students were purposefully selected using maximum variation sampling, which allows for different perspectives on the research problem by including students that represent a wide range of the characteristics of interest of the study (Patton 2002, Merriam 2001). We selected two students in each course type, one in each cluster in order to get various perspectives based on motivational type and perception of basic psychological needs satisfaction (theoretical and procedural validity). For the hybrid course, the two participants were in separate sections. However, for the large active and lecture courses, the two participants for each
course type were in the same section. This limitation was due to recruiting constraints, since those were the only students who agreed to participate in the interviews. Students picked their own pseudonyms, and the participants are summarized below in Table 4.2:

Table 4.2. Interview Participants

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional lecture</td>
<td>Ashley</td>
<td>Ben</td>
</tr>
<tr>
<td>Large active learning</td>
<td>Olivia</td>
<td>Mickey</td>
</tr>
<tr>
<td>Hybrid online</td>
<td>Katie</td>
<td>Betty</td>
</tr>
</tbody>
</table>

These students were invited via email to participate in semi-structured interviews with two members of our research team (See Appendix F for full interview protocol). We conducted two interviews with each participant (lasting 30-40 minutes each), and the students were given a gift card as an incentive. The interviews for all participants took place in our departmental interview room, and we wore casual clothing to help minimize power dynamics and build rapport with the students to help provide a non-threatening, relational environment (process reliability). The interview protocol was developed with guidance from an experienced math education researcher, and we tested the interview protocol with a first-year graduate student to make sure the questions would be clear to our participants. This student had just finished their bachelor’s degree in a STEM field and was close in age to our students, thus a similar participant (communicative validity).
Each question of the interview protocol was designed to relate to certain aspects of SDT (theoretical validity) (Table 4.3). Another member of our research team participated in the interview process. On the interview protocol, there were checkboxes under each question for the three constructs of SDT (competence, autonomy, and relatedness). During the interviews, this second researcher checked off when students had addressed these specific components in their responses (theoretical and procedural validity). We also asked the participants follow-up questions to help ensure we were understanding their experiences (communicative validity). As seen in Table 4.3, we also included some follow-up prompts that were specific to the course structure. We met after each interview to debrief and discuss our initial thoughts and perceptions (process reliability).

Table 4.3 Interview Protocol Mapped to SDT

<table>
<thead>
<tr>
<th>Question</th>
<th>Follow-up Prompt</th>
<th>Connection to SDT Constructs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can you walk me through a typical day in your calculus class?</td>
<td>What do you think about that group work? Is there any impact on your learning?</td>
<td>Competence, Autonomy, Relatedness</td>
</tr>
<tr>
<td></td>
<td>How do you feel about it?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hybrid: What do you do for that out of class component?</td>
<td></td>
</tr>
<tr>
<td>What is your most vivid memory so far this semester?</td>
<td></td>
<td>Competence, Autonomy, Relatedness</td>
</tr>
<tr>
<td>How in charge on your own learning do you feel in this class?</td>
<td>Choose a picture about who gets to make decisions about your learning. (Appendix F)</td>
<td>Autonomy</td>
</tr>
<tr>
<td></td>
<td>Can you talk about why you chose that picture?</td>
<td></td>
</tr>
<tr>
<td>I’d like to hear about the feedback you get in class.</td>
<td>Write types of feedback on index cards. Put them in order of most to least helpful. Why?</td>
<td>Competence, Relatedness</td>
</tr>
<tr>
<td></td>
<td>How do these methods of feedback impact your learning?</td>
<td></td>
</tr>
<tr>
<td><strong>Question</strong></td>
<td><strong>Q1</strong></td>
<td><strong>Competence, Autonomy</strong></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Do you ever give feedback to other people? Do your peers give you feedback? How does that affect your experience in this class?</td>
<td>Do you think your score reflects your ability to Master skills? Understand concepts?</td>
<td></td>
</tr>
<tr>
<td>Can you tell me about the exams in your class?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What math class do you expect to take next semester?</td>
<td>Why that class? How do you feel about going into that class?</td>
<td></td>
</tr>
<tr>
<td>You’ve told me a lot about your current class, how does that compare to math classes you’ve had before?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The interviews were audio recorded and transcribed, cleaned of any identifying information, and analyzed using NVivo 12 qualitative data analysis software (QSR International 2018) and Microsoft Word. The next phase of analysis used the process outlined by Saldaña (2016), which consists of different coding cycles. For first cycle coding, structural coding was used in order to identify what salient aspects of each course structure the participants were discussing. Structural coding is a categorization technique and results “in the identification of large segments of text on broad topics; these segments can then form the basis for an in-depth analysis” (Saldaña 2016, pg.100). This phase was conducted in NVivo.

Next, I used code charting as a method to transition to the second phase of coding. Saldaña describes code charting as making tables that “array a condensed paragraph of the participant’s primary data set (e.g. an interview transcript, observations) in one column, with the accompanying major codes in an adjoining column. This is particularly
helpful when there are multiple participants in a study” (Saldaña 2016, pg. 229). For each participant, I made a table in Microsoft Word with chunks of the transcript for each structural code (exams, group work, homework, etc.). I conducted this process for each participant for the first interview and then repeated the process for each participant for the second interview.

For the second cycle of coding, a priori codes were formed based on the three basic psychological needs of competence, autonomy, and relatedness as defined by self-determination theory. A priori codes are codes that are “determined beforehand to harmonize with the study’s conceptual framework, and to enable an analysis that directly answers your research question” (Saldaña 2016, pg. 71). These a priori codes were used to code the organized and condensed chunks of the transcripts that resulted from the code charting phase. This process was done for each participant for the first interview and then repeated for each participant for the second interview. During the second cycle coding phase, one reoccurring theme kept emerging from the data that didn’t quite fit into the a priori codes we defined, so a new code was created to capture this aspect of the students’ experiences (theoretical, procedural, communicative). Once this process was conducted for each participant, I looked across the participants to develop themes.

Throughout this process, I wrote memos to help document the progression of my analysis. Also, findings emerging from the data were discussed in-depth with the research team to gain multiple perspectives (process reliability).
4.7 Results

For each component in self-determination theory (competence, autonomy, and relatedness), quotes from participants in each course type will be presented to illustrate how specific aspects of each course structure are influencing students’ perceptions of their basic psychological needs satisfaction. The course type, interview number (first or second), and cluster number (defined in section 4.6) for each participant are included next to their quote.

4.7.1 Competence

*Asking questions while learning the material*

Students in each course type described the importance of being able to ask questions right as they were learning the material. The hybrid online course structure presented some challenges as students voiced concerns about not being able to ask a question during the online lectures:

“It’s very different. In high school, I was able to ask a lot more questions while going through the lecture. So, if I didn't understand something, I could just ask in that instant and not have to remind myself to ask about it later... it's different in person when you ask someone, because it's easier for them to explain it to you when you're sitting right in front of them.” –Katie (Hybrid, Interview 1, Cluster 1)

“Well I don't think I wanna do another hybrid class just 'cause I like having someone actually in front of me and being able to see it done in front of me. Instead of on a screen where, if I have a question, I can't just raise my hand and be like, ‘I don't understand’.” –Betty (Hybrid, Interview 1, Cluster 2)
Even though students in the traditional lecture course had opportunities to ask questions during the lecture, Ashley didn’t feel comfortable having to ask in front of the whole class, in part due to her lack of prior calculus experience:

“[The instructor] is just writing and keeps going. And I don't interrupt class 'cause then it slows them down...I could ask, but it's like I don’t wanna sound stupid in class. Everybody in there has already taken AP calculus.” – Ashley
(Traditional, Interview 1, Cluster 1)

Students in the large active learning course described the benefits of being able to ask questions during the group work time:

“And your partners also help you. And they make you feel more confident, especially if you don't know something and you ask them and they also don't know, then you can ask the teacher together” – Olivia (Large active, Interview 1, Cluster 1)

“Well the TA's do walk around and today someone asked a question in class, like she raised her hand and it got answered in class, so I feel like the teacher breaking up the lecture a little bit more with the worksheets, like that helped a lot...” – Mickey (Large active, Interview 2, Cluster 2)
Discussing material with peers

All of the participants talked extensively about the benefits of being able to discuss the material with their peers. The students in the hybrid online and large active learning course had regular opportunities each class period to interact with other classmates:

“... there's times when I don't know it and so I need someone to help me. There's times when my partner doesn't know, so we can work together.” –Mickey (Large active, Interview 1, Cluster 2)

“Something that really helps me is that we also have a group worksheet that we do afterwards. That's basically just what we did in class, except now you get to do it on your own. And you also work with a group, so it helps give you a little more confidence. And you also can ask for help without having to ask a teacher, and everyone's more or less on the same level” –Olivia (Large active, Interview 1, Cluster 1)

“When I'm working with them, they're explaining the curriculum a little bit better, like on a level that I can understand.”- Katie (Hybrid, Interview 1, Cluster 1)

“I like that [group work] because if I don't understand something from the lecture and it's on the group activity, the other people in my class can help me work through it more in-depth on a problem. “ -Betty (Hybrid, Interview 1, Cluster 2)
While the traditional lecture class didn’t have the consistent group work like the other two course types, the instructor did incorporate a few group activities throughout the semester. Ben and Ashley expressed the desire for more opportunities to interact with peers:

“It does help having someone to one-on-one ... 'cause the people that sit at my table ... one girl got 100 on the last test. So she is helpful when she can tell me, ‘Oh, this is what you need to do’.” - Ashley (Traditional, Interview 2, Cluster 1)

“I think the activities where you can work together are helpful...I think doing more of the group activities would be very helpful... 'Cause if I don't get it, somebody else probably can, and they can probably explain it pretty well, as kind of a student-to-student type of thing.” - Ben (Traditional, Interview 2, Cluster 2)

**Meaningful formative feedback**

Another aspect of the course that was contributing to students’ competence perceptions was the type of feedback they received from different assignments. Since Calculus I at this university is a coordinated course, all sections completed the same online homework assignments, so the participants shared many common perceptions about the homework, regardless of the course structure they were in. Many of our participants didn’t view the homework as providing meaningful feedback:
“I don't really get any feedback on homework... Our homework that we do is online so whatever grade you make is whatever grade you make. Your teacher doesn't look at that at all.” - Katie (Hybrid, Interview 1, Cluster 1)

“I don't know why I get it wrong...my homework's online. They don't even look at it.” - Ashley (Traditional, Interview 1, Cluster 1)

While Katie and Ashley didn’t consider the homework to be feedback, Mickey ranked the homework as the most helpful type of feedback he received in the class:

“...those ‘help me solve this’ things, I've already said that a lot, but they're really good because it walks you through the problem each step... if you get it wrong it gives a little message saying, ‘remember example and it’ll be like the chain rule.’ And then there's also the tool of using the textbook online.” – Mickey (Large active, Interview 2, Cluster 2)

Mickey was the only participant that discussed using the built-in help functions in the online homework platform.

The course structures that incorporated group work provided students with consistent formative feedback that they viewed as being meaningful:

“One the learning activities, [the TA] isn't too hard at grading, and she gives good feedback on those, too. So that's helpful.” – Katie (Hybrid, Interview 2, Cluster 1)

The group work also gave students the opportunity to give each other timely feedback as they worked problems together:
“Working together it just naturally comes through. Like, if I'm doing something wrong, somebody'd be like, 'Hey Mickey, I think you messed up here. You factored that wrong. Look at that.' And I try to do the same thing, where I'm not giving the answer, right. I'm like, ‘Hey make sure you check that. I'd check that before you keep going on’.”- Mickey (Large active, Interview 1, Cluster 2)

“Group activities they help me a lot just because that feedback from my other peers.” -Katie (Hybrid, Interview 1, Cluster 1)

4.7.2 Relatedness

Group work

The group work in the large active learning course helped students feel more connected with others, even though the enrollment was almost twice that of the other course types:

“…the group work helped because I made a pretty good friend in my class. At first, I was a little bit intimidated because I was like, ‘Oh, it's 80 people and everyone has their own screen, so I'm not going to really get to know anyone.’ But I did make a good friend that I walk home with every day now. And we got closer through the group work and just sitting beside each other every day in calculus”- Olivia (Large active, Interview 1, Cluster 1)

“I feel like organized community works better so working together I feel like I can still do the work on my own and many others can do the work on their own, but it’s
nice to know that everyone knows the stuff.” -Mickey (Large active, Interview 1, Cluster 2)

Betty felt that the group activities were the most positive aspect of the hybrid course:

“I think how much we get to work with each other. I think with group activities, I think it's very good at not only helping with your math skills but I guess your social skills. We work very well together. Even the different groups will work together if another group doesn't understand how to do stuff.” -Betty (Hybrid, Interview 2, Cluster 2)

While Katie also participated in group activities in the hybrid course and felt they were beneficial, her group had more of a “divide and conquer” approach, which could have led to her lower relatedness perceptions:

“We'll split up the group work. Like on the subjects that I know the best, I'll do those problems and they'll do the other ones...It's normally like front and back, and then it's a back page, so the two people on the left side of me do the front and the back, and I'll do the last page...And the other students in our group, like we'll switch it around so we can check each other's work.” -Katie (Hybrid, Interview 1, Cluster 1)

**Physical layout of the classroom**

One main difference between the course structures was the physical layout of the room. The traditional lecture and hybrid online classes were set-up the same way, with
students seated at round tables and there was a projector screen at both ends of the room. The large active class was held in a much larger computer lab. Students were seated in rows, and each student had their own computer screen so that they could follow along as the instructor wrote on lecture slides. Ben described how the round table format helped him feel more connected to his peers:

“I do like the way they have the tables set up, I think it builds kind of like a community with your table type of thing... I do like the people at my table. That's kind of nice. I made friends.” - Ben (Traditional, Interview 1, Cluster 2)

This was in contrast to the large computer lab set-up, which presented some challenges for Olivia:

“If you just look at the computer screen, it's like you're only there by yourself, so you might feel a little bit more isolated from the class because not everyone's looking at the same screen.” - Olivia (Large active, Interview 1, Cluster 1)

These different classroom layouts also created differences in students’ proximity to the instructor, which had an impact on Olivia’s relatedness perceptions.

“...but I still don't really ask a lot of questions just because I sit in the back and I'm not really close to the teacher. So unless the TA happens to walk by, I can't really ask a question. So I did ask questions when I sat in the front, like I used to sit in basically the first row and now it's just like [the instructor] wouldn't see me even if I did raise my hand and so I try to call TAs over, but usually I just ask my group 'cause we do have a group so that really helps.” – Olivia (Large active, Interview 2, Cluster 1)
Olivia being part of a group helped support her relatedness perceptions, even though the classroom layout wasn’t conducive to her feeling connected to the instructor.

**Creating a relaxed classroom atmosphere**

When conducting my observations of the traditional lecture and large active learning classes, one aspect that I noticed each time was the positive, relaxed atmosphere that the instructors created. There were instances during each of my visits where students were laughing at the instructors’ jokes related to mathematics in both classes. Mickey talked specifically about the classroom atmosphere when reflecting on the most positive aspect of the large active learning course:

“[The instructor] makes it a fun learning environment like on Halloween she dressed up and did a fun thing so that was cool... She's just funny and she'll make jokes, and one time she sang to memorize ‘low d high minus high d low’, she sang a song and that was pretty funny. And obviously it stuck with us.” -Mickey (Large active, Interview 2, Cluster 2)

### 4.7.3 Autonomy

There were a few aspects of the courses that were influencing students’ autonomy perceptions that were present in each course structure due to the coordinated nature of Calculus I at our university. These aspects included the pacing of the course and emphasis on mathematical notation.
**Pacing of the course**

The participants shared the perception that their instructors didn’t have the autonomy to be able to change the pace of the course if they needed to spend extra time on certain topics:

“I feel like I don’t have an input on how fast paced the course is...there's just a PowerPoint and that's it, like the PowerPoint is pacing the class, and not the students, and it's not the teacher’s fault, it's just that [the instructor] can't help it either.” - Olivia (Large active, Interview 1, Cluster 1)

“I guess it’s structured what day you have to do what. [The instructor] is just trying to get through it. 'Cause [the instructor] doesn't have the freedom to go, ‘Okay, I'll spend a little extra time on this one’.” - Ashley (Traditional, Interview 2, Cluster 1)

**Emphasis on mathematical notation**

Students also voiced frustration about the emphasis on proper mathematical notation on the exams:

“You're spending time remembering ‘oh, I have to write limit seven times’ rather than actually focusing on the problem, and I don't like how it's become about avoiding getting points taken off by how you write it, rather than getting the points by solving it.” - Ben (Traditional, Interview 2, Cluster 2)
“I feel like the equal signs don't affect the results of the problem, but if that's what I have to do, I guess that's just what I have to do.” -Katie (Hybrid, Interview 2, Cluster 1)

The hybrid online course structure had specific aspects that were influencing students’ autonomy perceptions. One issue was that students did not know what type of course it was when they were registering:

“Everyone in the class when we got to that class and they were like ‘this is a hybrid class you have to learn stuff online’. Everyone was like, ‘what?’” -Betty (Hybrid, Interview 1, Cluster 2)

Also, students had the perception that the out of class component in the hybrid course was just additional work they had to complete:

“I think I'd rather learn the lectures in class definitely, because I get behind on watching the lectures, just because I have to do the all these math assignments... just outside work. And then I have to watch a lecture outside of class, which I should be learning in class...So it's like, this is time taken away from my homework and studying that I could be having in class.” –Katie (Hybrid, Interview 2, Cluster 1)

Katie’s choice of the words “have to” and “taken away” illustrate her feelings of a lack of autonomy in the hybrid class.
Active role in learning

In regards to supporting students’ autonomy perceptions, the aspect that distinguished the course structures the most was the opportunity for students to be active learners. During the coding process, this theme didn’t seem to fit into autonomy as we had first defined it. So, we created a new code called “active role in learning” to account for this aspect that students were describing. After revisiting the literature, these descriptions were aligning with the concept of cognitive autonomy.

The large active learning course was a mixture of lecture and group work each day. This structure provided students with the opportunity to actively engage with the material on their own right after it was presented to them:

“So, we have lecture and then group work and then we also started integrating the group work within lecture. So right after she explains one concept we do part of the worksheet right off the bat so that's really helpful because you learn more from that if you actually do it yourself and you actually think it through and you know what things you have to work on. Because if someone just walks you through something, then chances are you won't catch everything, or you'll just assume that you know that as well, but you might not actually know it. Or you might be forgetting something important and then, once you actually walk through it yourself, you realize those things.” -Olivia (Large active, Interview 1, Cluster 1)

The traditional lecture course didn’t provide this same opportunity. Ben and Ashley both expressed the desire for a more active role in their learning during class:
“I think something, maybe like working practice problems as a class rather than just kind of like watching [the instructor] work practice problems. Because that ends up being just us copying down what [the instructor] writes rather than us like actually figuring out how to work them on our own.” -Ben (Traditional, Interview 2, Cluster 2)

“I don't think I get anything out of me just writing down what's on the board.” -Ashley (Traditional, Interview 2, Cluster 1)

This same perception was echoed by Katie in the hybrid online class. She felt that just watching the TA work additional practice problems in class wasn’t as effective as her actively engaging with the material:

“I'd say that when it comes to learning, especially with the lectures being online, if you didn't get a good foundation on it in the lecture, then when someone does examples, it doesn't really help because you're not actually figuring it out by yourself.” -Katie (Hybrid, Interview 1, Cluster 1)

These results are summarized in Table 4.4 below:
4.8 Discussion and Implications

Each one of the participant’s experiences offers some insight into how mathematics faculty can work towards making different course structures more motivationally supportive for students. Ashley’s experience of a lack of relatedness and competence suggests that a traditional lecture course may not be as motivationally supportive for a student that is taking calculus for the first time. Around 30% of students at research universities have not studied calculus in high school before enrolling at the post-secondary level (Bressoud 2015), so Ashley’s experience could be shared by many other students. A recent study using The Mathematical Association of America (MAA) national study of Characteristics of Successful Programs in College Calculus (CSPCC) dataset found that students who had not seen calculus before were significantly less confident in their Calculus I course. The authors suggest that instructors “demonstrate care for students and direct instruction towards students who are taking calculus for the first time” (Moore et al. 2019, pg. 5). Incorporating some active learning techniques that
would allow students like Ashley to ask questions in a less intimidating environment (rather than in front of the whole class) is one way that math faculty could support the motivation of students without prior calculus experience.

Students in the large active learning course talked extensively about how the group work helped them feel more connected to others in the class. This is important since students are more likely to internalize their motivation to learn in “contexts in which they experience a sense of belonging” (Niemiec & Ryan 2009). Also, the group work supported students’ competence perceptions by providing them with an opportunity to ask their peers, the instructor, and the TAs for help as well as explain the material to their group members and receive meaningful feedback. These qualitative findings suggest that incorporating group work into their calculus course could help math instructors create a more motivationally supportive classroom by increasing students’ competence and relatedness perceptions.

One salient difference in the three course types was the opportunity for students to actively engage with the material on their own during class time. Promoting ownership of their learning supports students’ cognitive autonomy, which encourages students to be more invested in the learning activity (Stefanou et al. 2004, Núñez & León 2015). Stefanou et al. 2004 illustrate the importance of facilitating cognitive autonomy in the classroom:

“Organizational and procedural autonomy support alone may not facilitate truly adaptive learning and motivation. Rather, the characteristics of ownership and justification of ideas, the construction of meaning, and the intentional self-reliance
used in critical thinking are at the heart of learning and motivation in the classroom… cognitive autonomy support may be the essential ingredient without which motivation and engagement may not be maximized” (pg. 109).

Students in the large active learning class described a more optimal structure for supporting cognitive autonomy than the other two course types. These students had the opportunity each class period to think through the material own their own right after it was presented in the lecture. Even though the hybrid online course had consistent group activities each week, the frequency of these activities was much lower than the large active learning course. Students in the hybrid course only worked on a group activity for 20-25 minutes one day a week. Instructors of a hybrid course could better support students’ cognitive autonomy by devoting more class time to group activities, rather than using the time to work additional problems for the students.

Katie’s perceptions of having to complete extra work in the hybrid course also led to her feeling a lack of autonomy. One way math instructors of a hybrid course could mitigate this perception is to be more explicit about the expectations of this course structure and the rationale behind why students will watch lectures outside of class (Tharayil et al. 2018). By faculty maximizing student perceptions of having a choice in when they watch the lectures and explaining the benefits of using class time for group activities, students’ feelings of autonomy could be better supported (Niemiec & Ryan 2009). Additionally, students were not aware that they were registering for a hybrid course. Providing this information to students ahead of time during registration could also support students’ autonomy perceptions.
A possible way that instructors of hybrid courses could address students’ frustration of not being able to ask questions during the online lecture is to provide a discussion board for students to pose questions. Discussion boards can help promote interaction in an online course (Gallini & Barron 2001). Students could answer each other’s questions, and an undergraduate or graduate TA could also help facilitate the discussions. By providing this extra source of feedback and interaction through the discussion board, students’ competence and relatedness perceptions could be better supported in a hybrid environment.

One shared perception of the participants across the course types was the emphasis on mathematical notation. Students viewed mathematical notation as just something they had to do or they would lose points on the exam, which led to a decreased sense of autonomy. Deci et. al (1994) claim three conditions are necessary to supporting autonomy: providing a meaningful rationale, acknowledging negative feelings, and using non-controlling language. Instructors could reframe students’ perceptions of using proper notation by explicitly addressing why notation is important. Instead of using phrases like “you will get points off on the exam,” explaining why it is important to write answers with correct mathematical notation could help promote students’ autonomy perceptions.

Another shared perception of our participants across the course types involved the pacing of the course. It is important to note that the participant comments regarding the pacing of the course were focused more on instructor autonomy, rather than student autonomy. However, in Olivia’s comment (see page 68) we can see that the amount of autonomy that instructors have impacts the level of perceived autonomy that the students
possess. This echoes the findings by Hagman et al. 2017, where the authors were studying the factors in introductory calculus courses related to students and instructors feeling that they were lacking sufficient time in class for students to learn the material. This research study used the terms of external and internal framing, where external framing refers to factors external to the student-teacher interactions within the classroom and internal framing refers to the amount of perceived influence that the students have in the course. The authors state that the level of framing dictates how much agency instructors and students feel they have to make inputs about the course and “external framing has a strong influence over how much control the instructor can yield to students (i.e. the internal framing)” (Hagman et al. 2017, pg. 3).

In our study, factors contributing to the external framing would include the aspects related to the coordinated nature of the course, such as common content, homework, and exams. Hagman et al. claim that “student perceptions of agency in the classroom are likely less based on external framing; their perception of having the most agency in the classroom will likely occur with weak internal framing, regardless if this is coupled with strong or weak external framing as they are often unaware of external factors” (pg. 3). However, this was not the case with my study. My participants were very aware of the coordinated nature of the class and had the perception that their instructor didn’t have the freedom to change the pace due to this coordinated structure, thus leading them to feel a decreased sense of autonomy in regard to the pacing.
4.9 Limitations and Future Work

One limitation of this study is that we only had one participant, Ashley, who did not have any calculus experience before enrolling in the course. Literature suggests that in addition to the current situational context, students’ prior experiences can also influence the extent to which they internalize their motivation (Ryan & Deci 2000, Ames 1992). Thus, students’ perceptions of the degree of competence, autonomy, and relatedness promoted by certain classroom structures, and therefore their type of motivation, are influenced by their prior math experiences, which we saw in Ashley’s interviews. Future work could explore this relationship further.

Another area for future research includes the pacing of the course. Our participants shared the perception that there was a set amount of content that their instructor had to cover, and they didn’t have the autonomy to spend more time on topics that students were struggling with. Future work could look into what essential topics need to be included in a first semester calculus course and optimal ways to pace the course to support student motivation.
Chapter 5

Conclusions

5.1 Addressing the Research Questions

This dissertation study addressed the overarching research question:

In what ways do variations in course structure affect aspects of student motivation and performance in Calculus 1?

The analyses of the survey data revealed that students in the hybrid online course had significantly lower autonomy, competence, and relatedness perceptions, as well as lower autonomous motivation scores, compared to the traditional and large active learning courses, even when controlling for student demographic characteristics. When investigating if these motivational components changed over the course of the semester, I found that students’ competence and autonomous motivation decreased throughout the semester, while their controlled motivation increased. These changes were consistent across the three course types. I also studied how these motivational components were related to performance in the course. Students’ competence, autonomous motivation, and controlled motivation were all significant predictors of final course average, with competence and autonomous motivation being positively associated with final grade and controlled motivation being negatively associated with final grade.

This dissertation study also sought to better understand what aspects of each course structure are supporting students’ basic psychological needs. The qualitative analysis of student interview data revealed specific aspects of each course structure that were related
to students’ perceptions of their competence, autonomy, and relatedness. Aspects that supported competence included students asking questions while learning the material, discussing the material with peers, and receiving meaningful formative feedback. Relatedness was impacted by providing students with group work opportunities, the physical layout of the classroom, and creating a relaxed classroom atmosphere. Aspects of the course structures that were related to autonomy were the pacing of the course, emphasis on mathematical notation, and being actively engaged in the classroom.

In sum, by addressing this research question, we have gained insight into factors that are impacting introductory calculus students’ motivation and performance in the course. These findings help to support the nationwide issue of the gatekeeper role of introductory calculus. By better understanding how course structures are related to students’ motivation and performance, we can work towards increasing student success in calculus, thus leading to more STEM students successfully progressing through their majors.

5.2 Limitations

The following are limitations of my study. These findings were from students at an R1 research university in the southeastern United States, where R1 is defined as doctoral universities with very high research activity per the Carnegie Classification of Institutions of Higher Education. Since I only studied Calculus I courses, these results may not transfer to other disciplines, other mathematics courses, or to students in upper level courses. I only focused on how these course types were related to student motivation, which is an affective factor. There are many other factors relevant to calculus success that were not the focus of this study, such as curriculum considerations.
It is important to note that there were a limited number of courses available for me to select from for this study. These courses weren’t pure pedagogical models typically found in the literature. However, they did contain varying levels of active learning components that warranted further investigation. The qualitative conclusions that suggested specific aspects of the course structures that support students’ motivation rely on the six participants’ experiences. These students were purposefully selected in order to gain a rich understanding of their perceptions; thus these findings are transferrable to students in similar contexts, rather than generalizable to all calculus students (Patton 2002, Merriam 2001). However, the mixed-methods design of this study lends itself to helping with this limitation through sample integration and weakness minimization, which concerns how the quantitative and qualitative sampling designs result in quality meta-inferences and the extent to which the weaknesses from one approach are compensated by the strengths from the other approach (Onwuegbuzie & Johnson 2006).

The quantitative phase of the study helped us gain a broad understanding of students’ motivation and performance in the different course structures. Since the students were not aware of which course type they were registering for ahead of time, this process resulted in a randomization of students to the three different course types. This randomization in the quantitative sample allows for stronger claims to be drawn, specifically claims about the course types having an “effect” on student motivation. The randomization also helps the study samples be representative samples of similar populations of calculus students. One limitation of the quantitative results was that there was only a statistically significant difference in students’ perceptions of their competence, autonomy, and relatedness and
motivational types between the hybrid course and the other two course types (traditional lecture and large active learning). However, through the rich descriptions gained through the interviews in the qualitative phase, it was revealed that students’ experiences in all three course structures were qualitatively different.

5.3 Implications for Research

This mixed-methods study used the theoretical framework of self-determination theory (SDT) to better understand the how course structures are related to student motivation in introductory calculus. Since most prior work using SDT has been primarily quantitative in nature (Filak & Sheldon 2003, Black & Deci 2000, Lavigne, Vallerand, & Miquelon 2007, Levesque-Bristol et al. 2010), the rich description of students’ perceptions gained from the qualitative piece of this study adds to the literature in this area. This work also supports and extends the SDT framework for the current population of introductory college calculus students. Also, previous studies of pedagogy in higher education have been mostly focused on comparing active learning to lecture based courses. This study adds additional insight by including course structures with varying levels of active learning.

The qualitative phase revealed student’s desire to have an active role in their learning in the classroom, which is an important component of cognitive autonomy support that merits future research. Núñez and Leòn (2015) call for future work on the impacts of the different types of autonomy support on student’s classroom experiences, since there is “very little empirical research on the three types of autonomy support” (pg. 279).
Additionally, Trenshaw et al. (2016) found that relatedness was the most salient basic psychological need for supporting student’s motivation in an undergraduate computer engineering course, and students’ autonomy perceptions weren’t as vital to their motivation. However, the aspects of their class that were designed to increase autonomy seemed to be more focused on organizational and procedural autonomy, not cognitive autonomy. The aspects incorporated into their course to support relatedness, such as collaborative learning, also support student’s cognitive autonomy as we found in this study. Trenshaw et al. (2016) found that “relatedness provides space for competence building” (pg. 1203). The findings from my study add to this idea and show that perhaps cognitive autonomy support is a possible link from relatedness to competence. Future research could explore this relationship further.

5.4 Implications for Practice

Results from this work can provide mathematics faculty with guidance on how to structure their courses in a way that is optimal for student motivation and engagement. This can empower them to succeed. This research shows there are specific aspects associated with different course types that are impacting students’ motivation. The following recommendations can be used by calculus instructors in all teaching modalities to help support students’ competence, autonomy, and relatedness perceptions, thus fostering autonomous motivation in their classes:

- Provide consistent opportunities to work with peers during class time
- Incorporate active learning opportunities during lectures
- Use a round table classroom format
• Explicitly discuss the importance of mathematical notation
• Create a positive, relaxed classroom atmosphere

This research supports the following suggestions specific to a hybrid course structure:

• Providing a discussion board for posting questions
• Explicitly explaining the expectations and structure of a hybrid course
• Informing students of the course type during registration

This study revealed that active learning experiences in the classroom were meaningful to students. In particular, the participants in the large active learning course discussed the benefits of breaking up the lecture into shorter parts and having students work on problems right after the material was presented. Also, having opportunities to consistently interact with their peers and the instructor through group work supported students’ basic psychological needs. However, it is important to note that incorporating active learning techniques into a course requires substantial work on the part of the instructor, and has been referred to as “ambitious teaching”:

Teaching practices that move away from traditional lectures to incorporate active learning experiences (e.g., facilitating small-group collaboration, pressing students to explain their thinking, engaging students in solving non-routine problems, and conducting whole-class discussion) are ambitious in that they are meant to support lofty educational goals including the promotion of deep conceptual knowledge and active student engagement with mathematics as well as the development of sophisticated views about the nature of mathematics. They are also ambitious in the sense that they require substantial institutional supports and
advanced knowledge, skills, and beliefs on the part of instructors. (Bressoud et al. 2015, pg. 104).

This quote, as well as results from my study, illustrate that some of these aspects of “ambitious” teaching are worthwhile yet can be challenging to implement effectively. This points towards implications for faculty development initiatives as well as implications at the departmental and institutional level. Faculty cannot be expected to move towards ambitious teaching without instructional support and time for development. Faculty development is needed in order to support instructors interested in creating more motivationally supportive course structures. This could involve workshops at universities or conferences, webinars, or faculty learning communities. These workshops could focus on providing instructors with knowledge about how self-determination theory can inform educational practice and developing skills related to implementing some of the aspects we found in this study that support student motivation, such as active learning techniques.

Faculty development initiatives specifically for instructors teaching in a hybrid course structure are also needed. Many students and faculty are not familiar or comfortable with this teaching/learning modality and need specific guidance on how to make this an effective teaching/learning strategy. Faculty not only need development in how to teach in a hybrid fashion but also how to mentor students in how to learn best from hybrid teaching.

Implementation of these more “ambitious” teaching practices also requires support at the departmental and institutional level. Departments could incentivize faculty
to try incorporating some of these aspects into their classes by offering professional development funds and/or course releases. In order to effectively facilitate group work, faculty need to have graduate or undergraduate TA’s in the classroom. This is especially true for large-enrollment courses. Workshops or courses targeted at helping TA’s develop the skills needed to assist faculty with implementing group work into the classroom is another way departments could help support faculty. Furthermore, one aspect of the course structures in this study that supported students’ relatedness perceptions was the round table format of the classroom. Ideally, this format should be used in conjunction with incorporating group work to help foster collaboration among students, like in the SCALE-UP classroom model (Beichner et al. 2007). Converting traditional classrooms into this format would require substantial support at the institutional level.

By incorporating the aspects into their courses that this research showed to enhance student’s competence, autonomy and relatedness, math instructors can work towards creating more motivationally supportive learning environments for introductory calculus students, like this one that Ben describes:

“I feel like sometimes you feel like you are a math student with other math students and sometimes you feel like you are alone and just listening to a lecture type of thing. Which I prefer the feeling of being a math student surrounded by math students, it tends to keep my attention more, helps me pay attention more, helps me to learn the content more I think. So creating that kind of dynamic I think would be pretty optimal.” - Ben
Appendix A

Informed Consent Letter for Survey

Calculus Study

Welcome! Dr. Karen High and Paran Norton are inviting you to take part in a survey. Dr. Karen High is a professor in Engineering and Science Education at Clemson University. Paran Norton is a graduate student at Clemson University, running this study with the help of Dr. Karen High. We are interested in better understanding students’ experiences in introductory calculus courses. Your responses are very important to us.

In this survey, we will ask you about your feelings towards your current calculus class and your experience with prior math courses. This survey should take about 10 minutes to complete.

Results from this survey will help mathematics faculty better understand factors that influence student success in calculus courses and provide more information about students’ experiences in math classes.

All data that you provide to us will be confidential. All data will be reported using pseudonyms and no identifying information will be used when sharing the results of this research. Only the researchers will have access to the electronic information that is securely stored.
If you have any study related questions or if any problems arise, please contact Paran Norton at Clemson University at pfisch@clemson.edu. This study is being done with approval from the Clemson University Institutional Review Board (IRB). If you have any concerns or questions about this research study, you may contact the Clemson IRB office at irb@clemson.edu.

By participating in the study, you indicate that you have read the information written above, are at least 18 years of age, been allowed to ask any questions, and are voluntarily choosing to take part in this research (which includes your responses to this survey and your course grades, which will be anonymized such that all identifying information about you is removed). You do not give up any legal rights by taking part in this research study. If you choose to consent, the prompt below will serve as your digital signature and your confirmation of consent.

I have read this form and have been allowed to ask any questions I might have.

Full name: 
Today's date: 

You may print a copy of this document for your records.

☐ I consent, begin survey.
☐ I do not consent.
Appendix B

Recruitment Email

Calculus Study

Hello __________,

My name is Paran Norton and I am a graduate student working with Dr. Karen High in the Engineering and Science Education department at Clemson University. We are conducting a study about students’ experiences in calculus as part of my research for my degree. I am reaching out to you since you are currently taking [name of course], and I am really interested in hearing your thoughts about your calculus class!

Your part in the study will include two interviews. I will ask you some questions about your experiences in your calculus class. It will take around 45-60 minutes of your time for each interview. We will provide you with a $20 Amazon gift card at the end of each interview as a thank you for your time!

If you are interested in participating or have any questions or concerns, please contact me, Paran Norton, at pfisch@clemson.edu or Dr. Karen High at khigh@clemson.edu.

Thank you!
Appendix C

Informed Consent Letter for Interview

Information about Being in a Research Study
Clemson University

Calculus Study

Description of the Study and Your Part in It

Dr. Karen High and Paran Norton are inviting you to take part in a research study. Dr. Karen High is a professor in Engineering and Science Education at Clemson University. Paran Norton is a graduate student at Clemson University, running this study with the help of Dr. Karen High. The purpose of this research is to get a better understanding of factors related to student success in introductory calculus courses.

Your part in the study will be to answer some questions about your experiences in your calculus class and your feelings about mathematics. This interview will be audio recorded. Paran may take notes during the interview to help the researchers remember to ask a question without interrupting you. There are no right or wrong answers; the researchers are interested in your thoughts and perceptions. It will take you about 30-60 minutes to be in this study.

Risks and Discomforts

There are no known risks associated with this project which are greater than those ordinarily encountered in daily life.

Possible Benefits

Results from this study will help mathematics faculty better understand factors that influence student success in calculus courses and provide more information about students’ experiences in math classes.

Incentives

You will be given a $20 Amazon gift card for participating in this study, which will be given to you at the end of the interview.
Protection of Privacy and Confidentiality

All data that you provide to us will be confidential. All data will be reported using pseudonyms and no identifying information will be used when sharing the results of this research. Only the researchers will have access to the electronic information that is securely stored.

The results of this study may be published in scientific journals, professional publications, or educational presentations; however, no individual participant will be identified.

Choosing to Be in the Study

You may choose not to take part and you may choose to stop taking part at any time. You will not be punished in any way if you decide not to be in the study or to stop taking part in the study.

Contact Information

If you have any questions or concerns about your rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-0636 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC’s toll-free number, 866-297-3071. The Clemson IRB is a group of people who independently review research. The Clemson IRB will not be able to answer some study-specific questions. However, you may contact the Clemson IRB if the research staff cannot be reached or if you wish to speak with someone other than the research staff.

If you have any study related questions or if any problems arise, please contact Paran Norton at Clemson University at pfisch@clemson.edu.

Consent

By participating in the study, you indicate that you have read the information written above, are at least 18 years of age, been allowed to ask any questions, and are voluntarily choosing to take part in this research. You do not give up any legal rights by taking part in this research study.
Appendix D

Situational Motivation Scale (SIMS) (Guay, Vallerand, & Blanchard 2000)

The statements below are related to your feelings of why you are taking this course. Students have different motivations for taking different courses, and we are interested in your motivations for taking this course thus far.

<table>
<thead>
<tr>
<th></th>
<th>Intrinsic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Because I really enjoy it.</td>
</tr>
<tr>
<td></td>
<td>Because I really like it.</td>
</tr>
<tr>
<td></td>
<td>Because it's really fun.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Integration</td>
</tr>
<tr>
<td></td>
<td>Because learning all I can about academic work is really essential to me.</td>
</tr>
<tr>
<td></td>
<td>Because acquiring all kinds of knowledge is fundamental for me.</td>
</tr>
<tr>
<td></td>
<td>Because experiencing new things is a part of who I am.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Identification</td>
</tr>
<tr>
<td></td>
<td>Because it allows me to develop skills that are important to me.</td>
</tr>
<tr>
<td></td>
<td>Because it's a sensible way to get a meaningful experience.</td>
</tr>
<tr>
<td></td>
<td>Because it's a practical way to acquire new knowledge.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Introjection</td>
</tr>
<tr>
<td></td>
<td>Because I would feel bad if I didn't.</td>
</tr>
<tr>
<td></td>
<td>Because I would feel guilty if I didn't.</td>
</tr>
<tr>
<td></td>
<td>Because I would feel awful about myself if I didn't.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Extrinsic</td>
</tr>
<tr>
<td></td>
<td>Because I feel I have to.</td>
</tr>
<tr>
<td></td>
<td>Because that's what I'm supposed to do.</td>
</tr>
<tr>
<td></td>
<td>Because that's what I was told to do.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Amotivation</td>
</tr>
<tr>
<td></td>
<td>I don't know. I have the impression I'm wasting my time.</td>
</tr>
<tr>
<td></td>
<td>I'm not sure anymore. I think that maybe I should quit (drop the class).</td>
</tr>
<tr>
<td></td>
<td>I don't know. I wonder if I should continue.</td>
</tr>
</tbody>
</table>
Appendix E

Basic Psychological Needs Scale (BPNS) (Levesque-Bristol et al., 2010)

The following statements concern your feelings about your experience in this course. Please indicate how true each of the following statements is for you given your specific experiences with this course thus far.

<table>
<thead>
<tr>
<th></th>
<th>Autonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I feel like I can make a lot of inputs in deciding how my coursework gets done.</td>
</tr>
<tr>
<td></td>
<td>I feel pressured in this course.</td>
</tr>
<tr>
<td></td>
<td>I am free to express my ideas and opinions in this course.</td>
</tr>
<tr>
<td></td>
<td>When I am in this course, I have to do what I am told.</td>
</tr>
<tr>
<td></td>
<td>My feelings are taken into consideration in this course.</td>
</tr>
<tr>
<td></td>
<td>I feel like I can pretty much be myself in this course.</td>
</tr>
<tr>
<td></td>
<td>There is not much opportunity for me to decide for myself how to go about my coursework.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Competence</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>I do not feel very competent in this course.</td>
</tr>
<tr>
<td></td>
<td>People in this course tell me I am good at what I do.</td>
</tr>
<tr>
<td></td>
<td>I have been able to learn interesting new skills in this course.</td>
</tr>
<tr>
<td></td>
<td>Most days I feel a sense of accomplishment from this course.</td>
</tr>
<tr>
<td></td>
<td>In this course, I do not get much of a chance to show how capable I am.</td>
</tr>
<tr>
<td></td>
<td>I often do not feel very capable in this course.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Relatedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I really like the people in this course.</td>
</tr>
<tr>
<td></td>
<td>I get along with people in this course.</td>
</tr>
<tr>
<td></td>
<td>I pretty much keep to myself when in this course.</td>
</tr>
<tr>
<td></td>
<td>I consider the people in this course to be my friends.</td>
</tr>
<tr>
<td></td>
<td>People in this course care about me.</td>
</tr>
<tr>
<td></td>
<td>There are not many people in this course that I am close to.</td>
</tr>
<tr>
<td></td>
<td>The people in this course do not seem to like me much.</td>
</tr>
<tr>
<td></td>
<td>People in this course are pretty friendly towards me.</td>
</tr>
</tbody>
</table>
Appendix F

Interview Protocol

• Can you walk me through a typical day in your calculus class?
  
  Competence
  Autonomy
  Relatedness

  Participating
  Interacting with others
  Group work
    ▶ What do you think about that group work? Is there any impact on your learning? How do you feel about it?
  Hybrid: What do you do for that out of class component?

• What is your most vivid memory so far this semester?

  Competence
  Autonomy
  Relatedness

• How in charge on your own learning do you feel in this class?
  Choose a picture about who gets to make decisions about your learning
    ▶ Can you talk about why you chose that picture?
I’d like to hear about the feedback you get in class.

Learning activities
Quizzees
Homework
Tests

- Write types of feedback on index cards. Put them in order of most to least helpful. Why?
- How do these methods of feedback impact your learning?

- Do you ever give feedback to other people? Do your peers give you feedback? How does that effect your experience in this class?

  Competence
  Autonomy
  Relatedness

- Can you tell me about the exams in your class?
  - Do you think your score reflects your ability to Master skills? Understand concepts?

  Competence
  Autonomy
  Relatedness

- What math class do you expect to take next semester?
  - Why that class?
  - How do you feel about going into that class?

  Competence
  Autonomy
  Relatedness
- You’ve told me a lot about your current class, how does that compare to math classes you’ve had before?

  Competence
  Autonomy
  Relatedness

**Background Information**

- What year are you at [name of university]?
- What is your major?
- What would you like your pseudonym to be?
## Appendix G

### Codebook for Basic Psychological Needs

<table>
<thead>
<tr>
<th>CODE</th>
<th>DEFINITION</th>
<th>EXAMPLE QUOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence</td>
<td>• Confident</td>
<td>“And your partners also help you. And they make you feel more confident, especially if you don't know something and you ask them and they also don't know, then you can ask the teacher together”</td>
</tr>
<tr>
<td></td>
<td>• Effective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Understanding material</td>
<td></td>
</tr>
<tr>
<td>Relatedness</td>
<td>• Connected with others</td>
<td>“But I did make a good friend that I walk home with every day now. And we got closer through the group work and just sitting beside each other every day in calculus”</td>
</tr>
<tr>
<td></td>
<td>• Belongingness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Interacting</td>
<td></td>
</tr>
<tr>
<td>Autonomy</td>
<td>• Authority</td>
<td>“I guess it’s structured what day you have to do what. [The instructor] is just trying to get through it. ‘Cause [the instructor] doesn't have the freedom to go, ‘Okay, I’ll spend a little extra time on this one.’”</td>
</tr>
<tr>
<td></td>
<td>• Choice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Decisions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Agency</td>
<td></td>
</tr>
<tr>
<td>Cognitive autonomy</td>
<td>• Active role in learning</td>
<td>“Because that ends up being just us copying down what [the instructor] writes rather than us like actually figuring out how to work them on our own.”</td>
</tr>
<tr>
<td></td>
<td>• Ownership of learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Engaging with material on their own</td>
<td></td>
</tr>
</tbody>
</table>
References


Michalski, G. V. (2011). Complementing the Numbers: A Text Mining Analysis of College Course Withdrawals. *Association for Institutional Research (NJ1).*


NVivo qualitative data analysis software; QSR International Pty Ltd. Version 12, 2018.


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