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Precalculus as a Death Sentence for Engineering Majors: A Case Study of How One Student Survived

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Abstract

Few college students wanting to major in an engineering discipline who begin in precalculus actually complete an undergraduate engineering degree program. One reason for this is students struggle through calculus I and II, known barrier courses for engineering majors. This research utilizes frameworks of future time perspective (FTP) and self-regulated learning (SRL) to explore one successful student's experience as he struggled through his mathematics courses, but was able to overcome those struggles and graduate with an engineering degree. A case study was constructed around this student, using quantitative data from his mathematics and engineering courses, as well as qualitative data in the form of an open-ended survey and interviews. A mathematics instructor, who modeled self-regulation strategies as he served as the student's mentor, was key to his success in passing the required courses in the calculus sequence. A model of interactions between FTP and SRL was developed based on an existing model and insights from this case study. By understanding the experience of one of the few successful students, educators are better equipped to assist other students and increase the number of students persisting in engineering, which will help address the global need for more engineers.

Introduction

Attrition in engineering education is a well documented problem, with 40 – 60 % of students who entered a university as an engineering major choosing to change majors or to leave the university (Budny, LeBold, & Bjedov, 1998; Geisinger & Raman, 2013; Moses et al., 2011; Ohland et al., 2008; Seymour & Hewitt, 1997). Calculus I and II are known barrier courses for engineering majors (Suresh, 2007). Performance in these barrier courses, as well as the interest and motivation to succeed in engineering, affect a student's persistence in an engineering program (Levin & Wyckoff, 1995; Suresh, 2007). Mathematics ability in general has been identified as the best single predictor of success in engineering (Levin & Wyckoff, 1988). Mathematics is considered a key to thinking like an engineer (Godfrey & Parker, 2010). By understanding the difficulties students face in mathematics courses, ways to help students overcome those struggles and be successful in their pursuit of engineering degrees can be identified.

Our university is located in the Southeastern United States, in a suburban setting. Roughly 26% of the new students enrolled each year declare an engineering major. At our university, historical data shows that students who declare an engineering major and take precalculus as their first math course are unlikely to complete an engineering degree program. Table 1 shows the number of engineering students matriculating between Fall 2006 and Fall 2010 (5 years) by initial mathematics course, the number of those who graduated in any major and those who graduated in engineering. The last column shows the percent of engineering students who graduated in an engineering discipline. Of those in this study, only 795 (20.41%) are female, and 3286 (84.34%) identified as Caucasian.

For our five years of data on graduation rates by mathematics course, over 80% of engineering students starting in precalculus either changed majors, left the university, or did not complete the engineering program within six years, compared to less than 40% in each of the other calculus courses, I – III. Many of the students who began in precalculus left the university or changed majors within their first year (Authors, 2015). The graduation rates were found to be significantly different for the five initial mathematics courses based on the Chi-square test ($p < 0.001$). The percentage of students starting in precalculus who graduated within six years was significantly lower than those starting in "Long Calculus" (precalculus review and calculus I stretched over two semesters) or one of the calculus courses (I-III). In fact, an engineering student starting in Calculus I is almost 3.5 (65.41/19.08 = 3.43) times more likely to graduate with an engineering degree than one starting in precalculus.

Table 1. Six year graduation rates of students majoring in engineering by initial math course, 2006 – 2010

Course	Enrollment	Graduated from University	Graduated in Engineering	Percent Graduated in Engineering
Precalculus	173	84	33	19.08
Long Calculus	695	482	281	40.43
Calculus I	1772	1460	1159	65.41
Calculus II	619	506	424	68.50
Calculus III	637	560	500	78.49
Total	**3896**	**3092**	**2397**	**61.52**

Note. “Long Calculus” is calculus I stretched out over two semesters, with roughly a third of the first semester dedicated to reviewing precalculus material.

In addition, Figure 1 shows the percentage of students starting in a specific mathematics course between Fall 2006 and Fall 2010 who graduated in each of the engineering disciplines offered at our university. The overall distribution is included at the end as a baseline. From this graph, we can see the majority of graduating engineers began in one of the calculus sequence courses. However, there are engineering disciplines with higher than average percentages of students starting in precalculus, like electrical, environmental, and industrial.

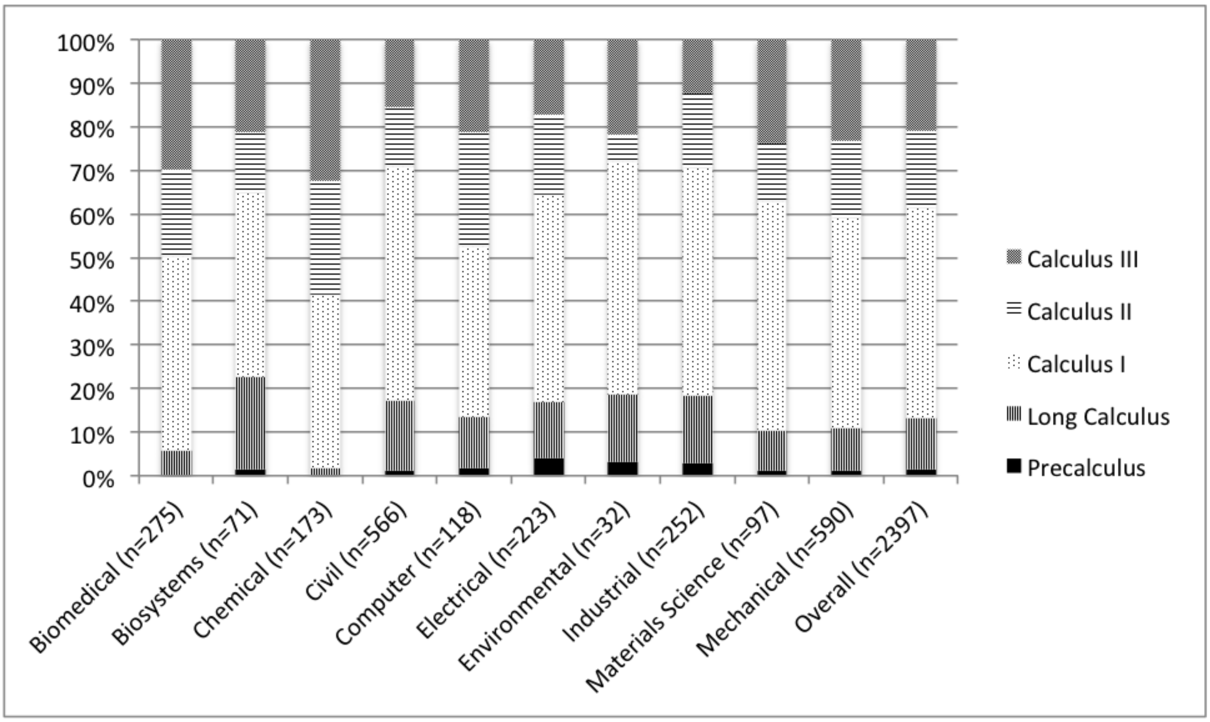

Figure 1. Percentage of engineering graduates starting in different mathematics courses by major, 2006 – 2010

This research seeks to understand the factors that contribute to students’ persistence in engineering when they began their studies in precalculus, a pre-college level mathematics course and struggled with their mathematics courses. Many of the students who remain in the program repeat one or more mathematics courses. The fact that so few are able to succeed in engineering programs after starting in precalculus begs the question: What is it about those students who do make it, and what about their experience might help future students stay on track?

To begin to answer this question, a single case study was conducted on an engineering student who started in precalculus and struggled throughout his mathematics courses. This case study will answer the following questions pertaining to the student’s completion of required mathematics courses:

1. In what ways did the student struggle in his required mathematics courses?
2. How did the student get through the required courses and stay on track for his degree program?

An additional research objective was to develop a theoretical model by which researchers can study similar cases in science, technology, engineering, and mathematics (STEM) education.

Theoretical Frameworks

Future Time Perspective

Future time perspective (FTP) examines how students' future goals affect actions they take in the present and what, if any, subgoals or contingent steps they recognize as being necessary to get there (De Volder & Lens, 1982; Husman & Lens, 1999; Miller, DeBacker, & Greene, 1999). With a contingent path, one cannot proceed to the next step without successfully completing the previous step (Husman & Lens, 1999; Raynor, 1981). For example, a student cannot take calculus II until successfully completing calculus I. Students with long-term goals better understand consequences of current class activities on their future goals. Because of this, they are able to plan ahead, create subgoals and find ways to make progress along their contingent path (Husman & Lens, 1999; Husman & Shell, 2008; Miller et al., 1999). Perceived instrumentality is the extent to which one sees the current task as being important to reaching one's future goal (Husman & Lens, 1999; Miller & Brickman, 2004; Miller et al., 1999). Instrumentality can be endogenous (the task is central to their future goal) or exogenous (the task is seen as merely a requirement to move to the next task, having no other value for their future goal) (Husman, 1998). Students' perceptions of instrumentality of their course work to their future goals have been found to be positively correlated with self-regulation and persistence (Miller, Greene, Montalvo, Ravindran, & Nichols, 1996). For students with required courses as "steps" in their path to their future goals, failure in the course will require them to repeat the "step," which increases the distance to their future goal.

Personally valued future goals are set by the student, and commitment to these goals sets the stage for the development of proximal subgoals used to reach their future goals (Miller & Brickman, 2004; Nuttin, Lorion, & Dumas, 1984). As the path of subgoals becomes more concrete and the student moves further along the path, they become more committed to their future goal (Markus & Ruvolo, 1989). The higher their self-efficacy for accomplishing their future goal (the more they believe they can attain it), the more effort they will put toward reaching it (Bandura, 1989). Once realistic proximal subgoals have been set, self-regulated learning in the form of self-observation, self-evaluation, and self-reaction play a role in completing these subgoals (Bandura, 1986; Miller & Brickman, 2004; Schunk, 1990).

Self-Regulated Learning

Self-Regulated Learning (SRL) has been defined as "an active, constructive process whereby learners set goals for their learning and attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their contextual features in the environment" (Pintrich, 2005, p.453). Self-regulated students use cognitive learning strategies (rehearsal, elaboration, organization) and metacognitive strategies (planning, monitoring, regulating) to understand course material and complete tasks (Garcia & Pintrich, 1994; Pintrich, 1999, 2004; Pintrich & De Groot, 1990; Zimmerman, 1986). Self-regulated students also manage and control efforts on tasks by managing their time, adjusting their study environment as necessary, and seeking assistance when needed (Garcia & Pintrich, 1994; Karabenick & Knapp, 1991; Pintrich, 1999, 2004; Pintrich & De Groot, 1990; Zimmerman, 1986).

Zimmerman and Martinez-Pons developed a framework with 14 self-regulated learning categories: self-evaluation, organizing and transforming, goal-setting and planning, seeking information, keeping records and monitoring, environmental structuring, self-consequences, rehearsing and memorizing, seeking social assistance from peers, teachers or adults, and reviewing tests, notes or textbooks (Zimmerman & Martinez-Pons, 1986). Studies have shown the use of self-regulation strategies improves academic performance (Bandura & Schunk, 1981; Kitsantas, Winsler, & Huie, 2008; Pintrich, 1999; Pintrich & De Groot, 1990; Zimmerman, 2008). Self-regulated students seek out information and assistance when they need help (Zimmerman & Martinez-Pons, 1988). Instructors can encourage students to ask for help by showing them the intrinsic value in learning and putting them in group situations where they can help peers (Newman, 2002).

Self-regulation is a choice made by students who are motivated to learn (Boekaerts, 1999; Pintrich, 2004; Zimmerman, 1994). In fact, "positive self-perceptions are assumed to be the motivational basis for self-regulation during learning" (Zimmerman & Martinez-Pons, 1986, p. 308). Students who are interested in the material, believe it is important, and believe they are capable of successfully completing the task are more likely to use learning strategies and be successful (Bandura & Schunk, 1981; Pintrich, 1999; Pintrich & De Groot, 1990; Zimmerman, 1986, 2005). Tabachnick, Miller, & Relyea, (2008). discussed how students starting in remedial courses, such as precalculus, have typically weaker self-regulation strategies, such as study skills, and that goals, both future and proximal, predicted self-regulation strategies. Students with poor or no self-regulation strategies have been defined as having maladaptive learning profiles (Nelson, Shell, Husman, Fishman, & Soh, 2015; Shell & Husman, 2008). Engineering students have been found to develop these maladaptive learning profiles while taking required foundational courses outside of engineering, like calculus (Nelson et al., 2015). These students either did not use any self-regulation strategies, were unsuccessful during self-regulation, or were not engaged enough during self-regulation to retain knowledge (Nelson et al., 2015; Shell & Husman, 2008).

A Model Connecting FTP and SRL

Goal-setting, a common strategy during self-regulation, is a key link between future time perspective and self-regulation (Bandura & Schunk, 1981; Zimmerman & Martinez-Pons, 1986). Miller and Brickman developed a model of future-oriented motivation and self-regulation that combines theories of future time perspective and self-regulated learning (Miller & Brickman, 2004). Their model proposes that one's future goals influence self-regulation in the present and encourage one to create proximal subgoals, which act as stepping stones on the path to their future goal. Once these subgoals are set, self-regulation is triggered to help set and accomplish tasks within each of the proximal subgoals. Those who see the tasks and proximal subgoals as being instrumental in reaching their future goals are able to see the value in completing the subgoals (Miller et al., 1999). If students are able to connect their current tasks to future goals, they will perceive having more control in navigating their path to their future (Husman & Lens, 1999; Husman & Shell, 2008). The Miller and Brickman model served as a basis for the model that we sought to develop for our case study, one that helps explain our case study and generalize results beyond our single case.

Method

Participant Selection

The population from which the case study participant was selected is students who entered the university committed to majoring in engineering, but who lacked the mathematical background to begin in a college level mathematics course. One of the cohorts from the Table 1 data had thirty-one such students who began in precalculus, the lowest level mathematics course in which an engineering major can begin. Of those, only seven students were either able to complete the curriculum or were still progressing and on track to graduate within six years when our study began. This particular cohort was chosen because we wanted to be able to interview the participant(s) as close to their graduation date as possible, and all were within six years from university matriculation. It was concluded two of the seven did not struggle in mathematics, based on their consistently high grades in subsequent mathematics courses and the fact that they did not have to repeat any mathematics courses. They likely should not have been placed in precalculus in the first place, and while they were included in the Table 1 data, they were not considered for this case study, since we were looking specifically for students who had difficulties in mathematics. The case study student, "Nick" (all names are pseudonyms), was selected out of the remaining five students because he fit our criteria and responded to our email invitation to participate in the study. Nick started in precalculus with engineering as his declared major, struggled in his mathematics courses (failed and repeated calculus II multiple times), but made it through an engineering curriculum and graduated with a degree in industrial engineering five years after matriculating.

Data Collection

Case studies serve to get at the depth of a phenomenon (Eisenhardt, 1989; Flyvbjerg, 2011; George & Bennett, 2005; Stevenson, 2004). It is of interest to understand the experience of our case study participant in his mathematics courses and his difficulties in mathematics. To fully answer the research questions about the student's experience, our case study is bounded by his engineering education experience, including any prior experiences that influenced or motivated him to major in engineering, his academic preparation prior to college, the advising he received while in college, and his experience during his mathematics-based courses.

Nick was first asked to complete an open-ended survey based on engineering and math identity. The survey asked questions such as, "Do you see yourself as an engineer/math person?" and asked him to describe a time he was recognized as an engineer/mathematician. It also asked what he wanted to do for a career and who (or what) was most influential to his career choice. Many of the open-ended survey questions were adapted from a study which looked at engineering identity and students' sense of belonging in engineering (Godwin & Potvin, 2015). The survey was modified by removing the questions that focused on physics identity and adding questions which asked about mathematics courses taken at the university, which ones were difficult, why the student found them difficult, and how the student overcame challenges.

The results from the open-ended survey were used to create the interview protocol for the first interview with Nick. The goal was to further understand why he chose engineering as a major, why he did not quit or change majors when he was struggling with math, and who helped or encouraged him the most during his college experience. During his first interview (80 minutes), Nick identified his mother, one of his advisors, and an instructor in the Mathematical Sciences Department who served as a mentor over multiple semesters as being instrumental in his success and persistence in engineering. These three individuals were interviewed (15 minutes each), which provided the opportunity to strengthen the case study by validating what Nick said in his interview (Yin, 1984). These interviews were followed by a second interview with Nick (50 minutes) to further clarify his mathematics background (high school), the consequences of starting in a non-college level mathematics course, and what the result would have been had he changed majors to something other than an engineering discipline. The survey was completed and all interviews were conducted during his final semester at the university.

Upon selecting this student and receiving IRB approval to collect all quantitative performance data for our case study, we realized from his transcript that he was in a section of the first year engineering course that was included in a separate study of engineering students' problem solving skills (NSF award number EEC – 1048325, "CU Thinking"), taught by the second author. As a result, we also collected examples of his course work, as well as exam grades from that course. A subset of this quantitative data (math placement test information, transcript grades, and first year engineering coursework) was used in this case study to strengthen and verify our results from the interviews (Creswell, 1998; Eisenhardt, 1989; Flyvbjerg, 2011; Perry, 1998; Yin, 1984). This rich data set allows for an in-depth case study and triangulation of data from multiple sources (Eisenhardt, 1989; Flyvbjerg, 2011; Yin, 1984).

Researcher's Perspective

The primary author is faculty in the Mathematical Sciences Department. During her years of teaching, she has taught many mathematics courses, including Long Calculus. She observed that many students in Long Calculus had a difficult time with the precalculus review material. Typically, these students came into the university with poor algebra skills. Because the main author has taught this course multiple times and has seen many students with the same problem, when the case study student was selected, it was suspected that he too came in with poor algebra skills, especially because he started in precalculus, an even lower level course than Long Calculus.

The lead author is also the registration coordinator for the Mathematical Sciences Department. Through her job experiences, she has seen the poor retention rates for engineering students starting in precalculus and Long Calculus. Some students who leave engineering for a major requiring different math courses say they leave because engineering was not what they thought it was. Others leave because they think engineering will be too difficult. But many cite that the math is too difficult. With so few students staying in the program who start in precalculus and Long Calculus, it was important to this author to identify what the faculty and advisors could have done to help motivate or better prepare the students who chose to give up on engineering because of difficulties in the required mathematics courses.

Data Analysis

Applying Theoretical Frameworks for Interpreting Nick's Experience

Because Miller and Brickman's theory (2004), which integrates future time perspective and self-regulated learning, was an appropriate model to begin mapping Nick's experience, Nick was asked to describe how he overcame his mathematical challenges and created stepping-stones on his path to his career goal. Nick had a clearly defined future goal, a distinct subgoal of graduating with an engineering degree, and within that subgoal were even more subgoals, one of which was to pass the required mathematics courses. Prior knowledge, future goals, and the creation of subgoals, or a contingent path, follow the future-oriented part of the Miller and Brickman model. The process by which he was able to motivate himself and work through the barriers he faced while progressing through the engineering program are supported and explained by the proximal self-regulation half of the Miller and Brickman model.Proximal self-regulation refers to the process by which students self-regulate while working through their proximal goals.

Coding and Interpretation of Data

Deductive coding (Onwuegbuzie & Combs, 2010) was used when analyzing the interview transcripts, where the elements within Miller and Brickman's model (2004) served as the pre-determined codes. Transcripts were analyzed using RQDA, an R package used to code qualitative data (Huang, 2016). Internal validity was established using pattern matching, which compares and matches data from multiple sources (Eisenhardt, 1989; Saldaña, 2011; Yin, 1984). When patterns were found that didn't correspond with an element in Miller and Brickman's model, a new code was created using emergent coding. Once all patterns relevant to Nick's engineering education experience were identified, the transcripts were examined again to identify all possible connections between the codes. Several iterations were conducted before finalizing the mapping of Nick's story to the new model.

The open-ended survey responses and interview data that had been coded as 'Proximal Task Engagement and Self-Regulation', an item within Miller and Brickman's (2004) model representing the strategies used and commitments made by a student while working on their current subgoal, were then subcoded in RQDA, this time using a codebook established from Zimmerman and Martinez-Pons' 14 self-regulation strategies (Chasmar, Melloy, & Benson, 2015; Zimmerman, 1986). Seeking social assistance from peers, teachers, or adults were consolidated to a single category, seeking social assistance, also referred to as help seeking (Garcia & Pintrich, 1994; Karabenick & Knapp, 1991; Newman, 1994; Pintrich, 1999). Likewise, activities related to reviewing records from tests, notes, or textbooks were consolidated to a single code, reviewing records. Pattern matching was again used to compare codes between the different data sources (Eisenhardt, 1989; Saldaña, 2011; Yin, 1984).

Quality Considerations

Several techniques were used to ensure that quality was maintained when making inferences from the data. First, sufficient time was spent with Nick during his final semester to build a relationship and get a good understanding of his story from his own perspective (Creswell, 1998; Onwuegbuzie & Leech, 2006). Nick opened up quickly and wasn't shy about elaborating when asked questions about his experience. Second, by utilizing multiple sources of data, the findings could be triangulated (Creswell, 1998; Eisenhardt, 1989; Miles & Huberman, 1984; Onwuegbuzie & Leech, 2006; Stake, 1994; Yin, 1984). Interviews with his mother, advisor, and instructor, along with his academic transcript, confirmed his self-reported journey. Throughout the research project, meticulous notes were taken so an outside researcher could follow the process (Eisenhardt, 1989; Onwuegbuzie & Leech, 2006; Yin, 1984). Lastly, this manuscript was shared with the participants (Creswell, 1998; Miles & Huberman, 1984; Yin, 1984). No corrections were necessary, but participants provided more details for clarification.

Results and Discussion

Overview of Nick: Past Experiences and Values

Nick was raised in a large city on the Southeastern coast of The United States. At the age of 10, Nick's father became ill and passed away. Nick and his mother developed a very close bond. Throughout his youth Nick participated in sports and church activities. He formed a bond with many of the coaches and church members. His devotion to his religion continued into college when he helped start a Christian fraternity on campus. As an athlete in grade school, he quickly developed into a leader for the younger athletes and understood the corresponding responsibility. Nick enjoyed his leadership role and wanted to be recognized as a leader in future endeavors.

> If I wanted the younger kids to be doing good in school, then I needed to be doing good in school … [It was] me showing value in the grades at the same time and showing that basketball and football are a privilege after you perform in the classroom. (Nick)

Nick is Caucasian, and at the time of our initial interview, was 22 years old.

Nick's Future: Interest, Future Goal and System of Proximal Subgoals

Nick attended a very small, private, Christian school with grades kindergarten through 12th. Because it was a new school, the administration relied on teachers to establish the curriculum. After completing an assignment in history class on World War I ace Eddie Rickenbacker, his teacher (the wife of one of the male leaders in his church, who had also served in the Unites States Air Force) asked Nick if he had considered going into the Air Force. At the time he hadn't considered it, but he soon decided he wanted to be an Air Force pilot (Future Goal). He was not accepted into the United States Air Force Academy after graduating from high school, so he decided to attend college elsewhere. It was important to Nick to find a way to pay for college. "I always wanted to get school paid for so mom didn't have to worry about that." So he pursued a scholarship through the Reserve Officers' Training Corps (ROTC). He filled out the ROTC scholarship application indicating he would major in an engineering discipline (Subgoal), something he knew the Air Force was looking for (which was confirmed by his ROTC advisor), and was given a full scholarship and five years to complete an engineering degree program at a southeastern land grant institution.

Luke was one of Nick's ROTC advisors at the university and had served in the military for more than 25 years. As Nick's advisor, he was charged with helping Nick map out his degree program and stay on track so he could graduate on time. Luke advised roughly 50 students each semester. As an engineering major, Nick was required to take calculus I - III. These math courses serve as proximal subgoals and contingent steps necessary for the engineering degree. Proximal subgoals here are similar to what Miller and Brickman (2004) refer to as proximal target goals in their model. Nick understood the importance of these math courses for his engineering degree (Perceived Instrumentality). Nick saw the required calculus courses as having exogenous instrumentality (Husman, 1998) for his future goal, because he did not believe that he would use calculus as an Air Force pilot, but if he couldn't complete the required mathematics courses, he wouldn't graduate with the engineering degree he deemed necessary to be an Air Force pilot.

Luke started in a common first year engineering program, which was required of all engineering majors at his university. Students cannot matriculate into an engineering major until they have completed certain courses, including calculus I and II. Through the open-ended survey, Nick revealed he originally wanted to go into mechanical engineering, but when Luke realized mathematics was not one of Nick's strengths, he encouraged Nick to major in industrial engineering instead, which only requires calculus I - III, while mechanical engineering requires three additional mathematics courses, all with calculus III as a prerequisite. Even Nick recognized the importance of strong math skills for mechanical engineering: "I was originally thinking mechanical engineering, but I was struggling with math early." Luke's influence on Nick's decision to pick industrial engineering is represented in the model by the connection from External Reactions (Advisor) to System of Proximal Subgoals.

Nick's Mathematical Ability Entering College: Past Experiences, Knowledge/Retention, and Self-Concept of Ability

Nick explained that his troubles in mathematics began in middle and high school when a teacher for algebra I and II was brought in who did not seem to care about or follow the standard curriculum. Nick had a different teacher for precalculus who assumed the students knew algebra. The teacher quickly became frustrated when he realized the students had deficiencies he did not have time to cover in class. The school ended up bringing in another teacher midway through the year to finish the precalculus course, but as Nick observed, "[I] still didn't learn as much as I needed to in that second half."

All incoming students at our university, are required to take a math placement test to determine which mathematics course they should begin in. Without Advanced Placement or transfer credits, Nick could place into either Precalculus, Long Calculus, or calculus I. The year Nick matriculated, the placement test was scored on a scale of 1 to 6. Students earning a 5 or 6 on the placement test were placed into calculus I. Students earning a 3 or 4 were placed into Long Calculus. Those with a 1 or 2 began in Precalculus. Typically students took about an hour to complete the 50 question placement test, but Nick spent more than an hour and a half on the test, and scored a 1. Half of the placement test questions covered algebra only. His weighted subscore for the algebra questions was 10.25 out of 25, indicating he was very weak in algebra.

Nick's weakness persisted even in his second semester of college. Figure 2 is an example of Nick's work from a problem in his introductory engineering course. At one point he needed to solve for R, the value of a resistor. It was a very basic equation, 15 = .4 R, but instead of just writing the solution to a straight forward division operation, R = 37.5, Nick needed to explicitly divide both sides by .4 first and cross out the form of one (see Figure 2). Explicitly writing out this step is a step college students would be expected to skip.

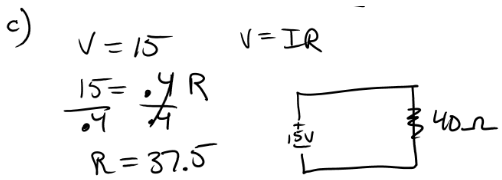

Figure 2. A sample of Nick's work from his introductory engineering course demonstrating his weak algebra skills

Nick attributes his mathematical deficiencies to the poor instruction he was given in high school. Because of this, he never questioned his ability to complete an engineering degree. When asked if he thought someone who is not a math person could be a successful engineer, he replied:

> I think that if math isn't your best strength, but you have the motivation to get through and that sort of stuff, then that's definitely possible, and that you don't need to know everything behind there, but you can still do it. (Nick)

When I asked his mother, advisor, and calculus II instructor why they thought Nick had a difficult time with college mathematics, they all said they thought it stemmed from poor preparation in high school.

> The math teacher that he had in junior high, there was some inconsistency there when one of the algebra teachers ... I think it was just the methodology... if you've got a good teacher that can communicate clearly and teach algebra, it lays the foundation for the rest of the classes beyond that. If you don't have a teacher that can teach, she may know in her head what she's doing, but she can't portray that to the kids. So I think that was the bottom line. (Mother)

> [Nick's] struggle was really math. Good at everything else and I think he just didn't have the tools from high school that would allow him to be successful easily, at all easily. (Luke, ROTC advisor)

> One of the real weaknesses I found for him, which I think is typical of a lot of students, he just did not have the necessary background. He did not know the algebra and trig and geometry. (Morgan, calculus II instructor)

Where and How Nick Struggled: Proximal Target Goal

Nick entered college with significant mathematical deficiencies which were evidenced by his math placement test results, placing him in precalculus. After taking the mathematics placement test before his freshman year, Nick understood he was behind in mathematics. "With the Air Force, they let you take 5 years. It's like, okay, well I have some extra time so I can take this extra class, [precalculus], and be able to catch back up in the math." He recognized that the material was important for subsequent courses, but because of how the course was graded, he didn't put in as much effort as he later realized he should have. "One of the things that probably made it easier not to work as hard was the fact that it was pass or fail. Okay, well, I'm going to need this stuff later, but it's pass or fail." Not only did he find the structure of the course un-motivating, but he was also in Arnold Air Society, a service organization for United States Air Force cadets, where he had to get up at 4:00 in the morning for rigorous physical trainings (PTs) after which he had to attend precalculus class at 8:00 AM.

> I was trying to pay attention in that class, but it's 8:00 in the morning after I just got out of two back to back PTs … I'm already worn out and tired and all that stuff and then, like I still was going to class … I just wasn't in prime learning mode. (Nick)

He passed precalculus his first semester and observed that "at the end, I knew that I wasn't doing really well, but I knew it was enough to pass."

The following semester Nick completed calculus I. Nick recognized that he had holes going into calculus I. "I didn't do as good in [precalculus] as I should have, then that kind of carried over to [calculus I] also." While he passed the first calculus course with the C required by engineering to move on to calculus II, he barely earned it. His test grades from calculus I were 78, 53.5, 60, and a cumulative final exam grade of 52; he had below average performance on all but the first exam. While his test grades indicated he wasn't mastering the material, his daily average (94.3) indicated he was putting in the effort and time needed to complete daily assignments and homework. He finished the course with a 70.02 average, just barely above having to repeat the course.

The fall of his second year he took calculus II with Morgan, a faculty member in the Mathematical Sciences Department. Nick realized he did not retain as much of the calculus I material as he would need. "I had holes in [calculus I]." It was not going well, and he did not want an F on his transcript, so he decided to officially withdraw from the course, but asked Morgan if he could continue to attend class and take notes.

> 'Sure, that's fine with me,' [I told him]. And, I guess one of the first things that impressed me, I've had students through the years that always ask me that and then they may show up one or two more times and that's it. Hardly ever have anyone actually do it all the way to the end and he did. He came, I think nearly every class, participated in everything we did. (Morgan, calculus II instructor)

The next semester he retook calculus II, but this time his instructor, who was also serving in an administrative capacity in the department, was not as available or helpful during office hours as Nick had hoped. Nick felt alone.

> [The instructor] didn't have a whole lot of time outside of class and he made it known that that was the case. I didn't feel comfortable going to him and the times that I did, he was very short and it's like 'we went over this in class'… You feel like you have a lack of options as far as what to do. So you feel like you just have to sit there and struggle when you don't have anything else that you can do or anybody else you can kind of turn to for help. (Nick)

Nick ran into Morgan during the semester in which he was taking calculus II for the second time, and when they discussed how class was going, Nick explained he was still having a difficult time with the material. Morgan offered to let Nick come by Morgan's office and ask questions if he wanted help. Nick asked if the offer was a serious one, and when Morgan confirmed, Nick took advantage of the offer. Nick began meeting with Morgan between the first and second exams. "I got better, I just didn't get enough to kind of repair the damage."

This is evidenced by Nick's increasing exam grades that semester, which progressed from 36.5 on the first exam to 54, 58.25, and 68 on subsequent exams and the final exam, respectively. And again, his daily average (94.66) showed he was trying. This was enough for him to pass the course with a D, but because engineering courses required a C or higher in prerequisite courses, it wasn't enough to move on to calculus III.

What Nick's transcript doesn't show, but what came out in an interview with him, is that he tried to take calculus II the following summer after his second attempt to earn and transfer in the required C, but he "couldn't keep up. Especially with the shortened summer [class]." He took the course a fourth time the fall of his third year with yet another instructor. This time he worked with Morgan from the beginning of the semester and finished the course with the required C.

Throughout college Nick didn't fail any of his courses. He made one D (in calculus II), but ended with nine Cs. An interesting point when analyzing his transcript is that eight of those Cs were either in mathematics courses (calculus I, II, and III) or courses that are very math oriented (engineering problem solving, probability and statistics I, statics, probability and statistics II, and physics with calculus II). Because it took four attempts for Nick to achieve the required grade of C in calculus II, this is the course chosen to primarily focus on as the Proximal Target Goal in the model.

Modifications to the Existing FTP and SRL Model

To address our research objective to create a transferable model (Miles & Huberman, 1984), we modified Miller and Brickman's model (2004) to explain Nick's engineering education experience (see Figure 3). Items and connections indicated by dashed lines were not in the original model, but were identified while coding the interview transcripts as something that could augment Miller and Brickman's model to reflect this case study.

General & Task-Specific Problem Solving and Learning Strategies from the Miller and Brickman (2004) model was later changed to Personal Responsibility by Brickman (Brickman, 2013) which is included in Figure 3. Personal responsibility is a student's "overall level of commitment to completing established personal goals even when they are difficult" (Brickman, 2013; Nelson, Low, Stottlemyer, & Martinez, 2004). This item change accurately reflects Nick's experience in that he had to, and chose to, repeat calculus II multiple times to continue in the engineering program and achieve his goal of becoming an Air Force pilot.

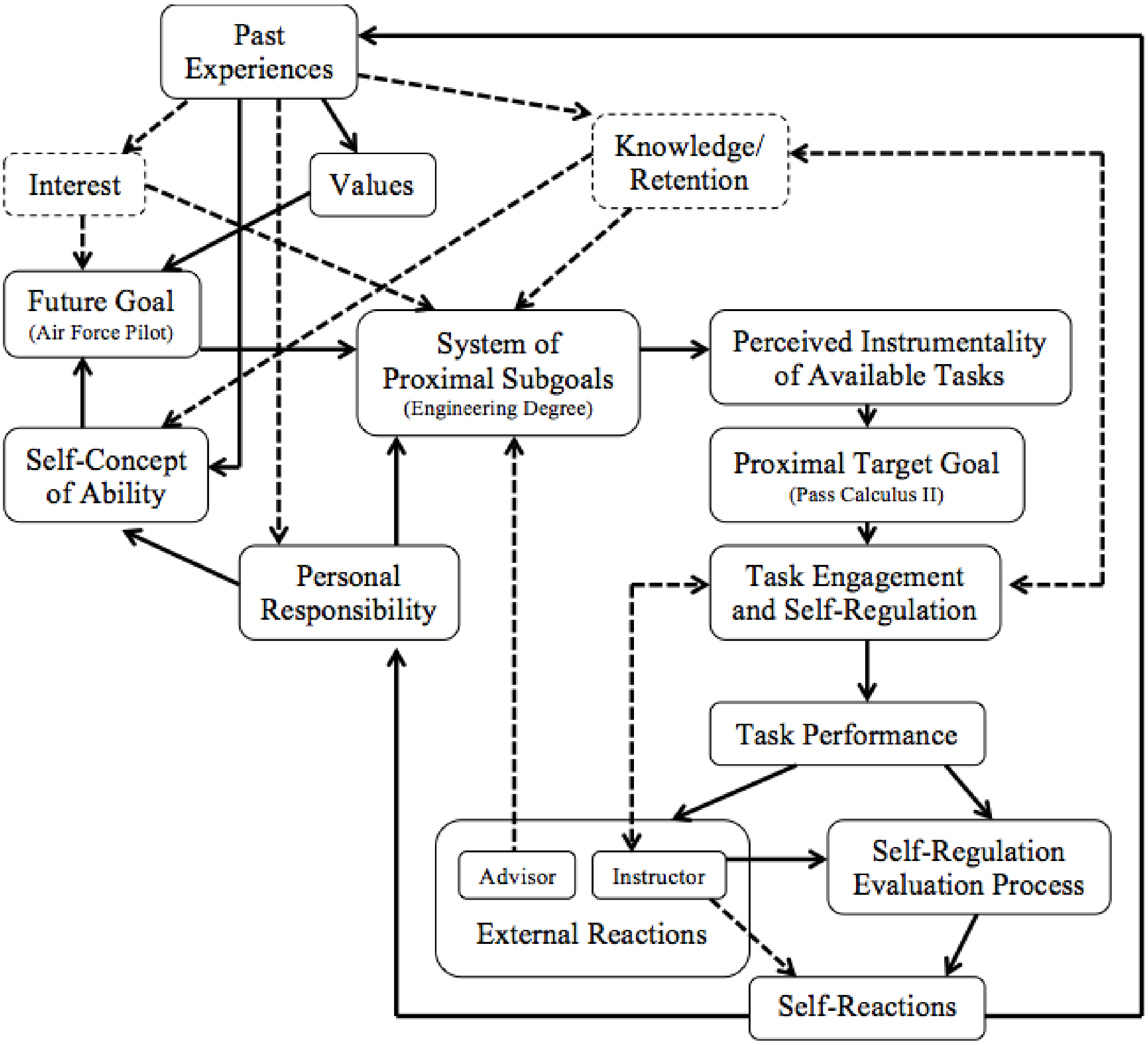

Figure 3. A model of connections between FTP & SRL based on Nick's experience

New Model Items

Nick developed a strong interest not only in becoming an Air Force pilot, but also in engineering. This came out in the analysis of statements from Nick such as, "I always liked planes, so if I could be flying planes then I'd definitely do that," and "I knew that I wanted to do engineering. I think it was mostly because it was more hands on. It was problem solving, I like that part of it." His mother said, "Mechanically, Nick has always been very interested as far as cars and engines and movement and that just transpired into flight." Part of his motivation for becoming a pilot and majoring in engineering was his inherent interest, and thus, it warranted a place in the model as "Interest", stemming from "Past Experiences" and leading to "Future Goals."

The fact that Nick didn't have the necessary mathematical knowledge to excel in calculus and had a hard time retaining the information from one course to the next also frequently became evident during interviews with participants who knew him. His poor math background and inability to retain as much as necessary was the reason he had to repeat calculus II as many times as he did.

> He had not retained as much of the [calculus I] material in detail like we needed so he was constantly struggling and asking those questions, well why... well, what you were supposed to get in [calculus I]... (Morgan, calculus II instructor)

Because of the importance of knowledge and retention to Nick's success, it was important that knowledge and retention be added to the model of his experience. As Nick was working through math courses, he was drawing on his previous knowledge and committing more knowledge to memory. This relationship between knowledge acquisition and retention and learning can be seen in the model by the two-way connection between Knowledge/Retention and Task Engagement and Self-Regulation. This connection is supported by cognitive learning theory related to how new ideas interact with one's prior knowledge, creating new meaning which is then linked, organized, and retained in memory (Ausubel, 2000; Schunk, 2008).

Nick's self-efficacy was also impacted by his knowledge acquisition and retention, illustrated by the connection between Self-Concept of Ability and Knowledge/Retention. When describing what it felt like to struggle in his mathematics courses and how he knew he was having a hard time, he referred back to his deficiencies from grade school.

> … if I don't have the background for this and it's like, I can't do this on my own because even if I read this stuff and went through all the things by myself before class, all this other stuff, then I'm still going to be lost. (Nick)

When Nick was asked if he struggled in any of his engineering courses, he said "some of the stuff that has calculus in it." Nick withdrew from dynamics, an engineering course with a prerequisite of calculus II, because he "wasn't doing well" in it, but the industrial engineering department ended up dropping it from the curriculum so Nick did not have to retake it. Nick's decision to major in industrial engineering instead of mechanical engineering, because he knew he did not have the necessary mathematics skills to be successful in the mechanical engineering curriculum is represented by the connection between Knowledge/Retention and System of Proximal Subgoals.

Items Removed from Existing Model of FTP and SRL Interactions

Nick was determined to become an Air Force pilot, and he was convinced he needed to major in engineering to reach that goal. Because he didn't even consider alternatives, Knowledge of Possibilities in Miller and Brickman's model (2004) didn't apply to him and so was excluded from this case study model. Also appearing in Miller and Brickman's model, but excluded from the study model, are Perceived Immediate Context and Available Tasks, Task-Related Outcome and Efficacy Expectations, Cognitive Evaluation of Context, and Present Task Value. The purpose of this study is to clearly explain why Nick didn't quit and how he was able to make it through those barrier courses when he was mathematically weak. The authors thought specific assignments in his courses did not add more insight into his engineering education experience and therefore "task" in the revised model refers to the current semester course he is working through, rather than specific assignments within that course.

Nick and Morgan's Relationship: Task Engagement and Self-Regulation

Nick and Morgan worked together in the afternoons, on some weekends, and even late in the evenings, sometimes past midnight. When asked how often they met during his fourth attempt at calculus II, Morgan's response was, "I think it would be easier to ask when we didn't meet. It got to the point I think it was like nearly every afternoon." The relationship Nick and Morgan developed, and the importance of it to Nick's success on his path to an engineering degree, is represented in the model by the two-sided connection between External Reactions (Instructor) and Task Engagement and Self-Regulation.

Nick's Self-Regulation Strategies

On the open-ended survey and during the interviews, Nick was asked about his mathematics courses and how he was able to overcome difficulties with the material. Several of Nick's responses corresponded to Zimmerman and Martinez-Pons' self-regulation strategies (Zimmerman & Martinez-Pons, 1986).

GOAL SETTING AND PLANNING: When Nick withdrew from calculus II, he chose to continue attending and participating in class. This was evidence of planning on his part to make sure he was prepared for the next time he attempted to take the course. While he was working with Morgan, they had tutoring sessions frequently, but Nick specifically planned tutoring sessions before an exam.

INFORMATION SEEKING: Nick mentioned that in one of the last semesters of calculus he started using online resources to help him understand the material. When asked what kind of things he would try when he was stuck working a homework problem, his response was:

> Like looking up stuff online. I don't even know if I knew that really existed when I got here freshman year, but the Khan Academy stuff. I'd try to look up stuff online later and that helped. And I ended up kind of trying to use that to study later on and stuff too. (Nick)

KEEPING RECORDS AND MONITORING: Nick made it a point to attend class regularly. "It's like very, very rare that I miss class." Even after he withdrew from calculus II the first time he took it, he continued to attend and participate in all class activities. These show signs of monitoring his progress during his education. Nick did not make explicit reference to keeping records.

REHEARSING AND MEMORIZING: On the open-ended survey, when asked how he was able to overcome mathematical challenges, he said "Reading over the chapter before class helped a lot," and "It also helps going home and practicing the same stuff you learned in class that day that night." Both reading before class and reworking course problems are examples of rehearsing the course material.

SEEKING SOCIAL ASSISTANCE: This is unquestionably the most influential strategy Nick used. Nick would ask for help when he needed it. He would go to student-lead instruction sessions outside of class and ask questions. He would visit tutors at the university tutoring center to get help on the course material. He asked all of his instructors for help during office hours as needed. When Morgan offered to help Nick the first time they ran into each other, Nick continued to seek Morgan for assistance. Even after his first semester working with Morgan, Nick continued to visit Morgan's office and ask for help on the calculus material over multiple semesters.

SELF-EVALUATION: During interviews Nick brought up being confused in class, but not wanting to ask questions. He didn't want to stop and ask the teacher in class because "it is so fast-paced … if you ask a bunch of questions and you're not getting it, then you're not getting taught the rest of the stuff that needs to be taught." He didn't want to ask the other students sitting next to him because "they're trying to focus on the class too and the teacher's still going so, you know, it's almost distracting them from learning." When discussing the frustration he felt when he went to office hours with the calculus instructor who was not helpful, Nick said "Yeah, you might have gone over this in class 10 minutes ago, but I didn't understand it. And so, if I didn't understand that, I need you to explain it to me again." All of these examples show Nick was able to self-evaluate and determine when he wasn't understanding the course material.

External Regulation Strategies

Nick attributes his eventual success in calculus II to Morgan, who privately tutored him over the course of three semesters. During their sessions together, Morgan modeled self-regulation strategies for Nick.

ENVIRONMENTAL STRUCTURES: When Nick was having a hard time focusing or was getting tired during their tutoring sessions, Morgan would have him go outside and jog or do calisthenics.

> [Morgan] would be 'Alright, let's do some push ups.' It wasn't anything like you have to do this or anything else. It was like, 'You've got to wake up, let's go for a quick jog real quick, get your blood flowing again.' That was great in that part of it too and the motivation behind that. You've got to keep

> working, you've got to keep working and even working those long hours and stuff, that was really motivational for me too. (Nick)

Morgan confirmed this during the interview when asked to describe when Nick was getting frustrated or struggling.

> One of the funny things I finally discovered was because of his ROTC background, I would sometimes make him do calisthenics and go out and run. Anything to try and get some energy out, or get him pepped up again. That actually seemed to work, and I was really shocked, because, actually, I was in a classroom one day working [with Nick] and it seems like he had a test or something coming, and he was not doing good that day. I was like, 'Okay, either you've got to get in focus or we need to stop because it's not helping.' [Nick] said, 'No, we can't, we can't. We've got a test.' I said, 'Well, how are we going to get you focused?' [Nick] said, 'I don't know. I don't know.' I was sitting there and I thought, he's ROTC. I know he loves sports. I thought, okay, come here. I took him outside and I just started drilling him. He did not flinch one time. It was like okay, okay. Then we went back upstairs. I said, 'Now, go to the board and do those problems.' It actually worked. He got a big kick out of it too. (Morgan)

Morgan would also take Nick from the office to one of the classrooms and let him work problems on the board. Morgan attended to Nick's individual needs by changing their work environment, which helped Nick get in the right frame of mind and focus in order to continue working through the calculus problems.

REHEARSING AND MEMORIZING: When Nick and Morgan worked together, Morgan would often work an example problem using the concept Nick was asking about and then Morgan would give Nick problems to work through himself, changing each problem slightly, and increasing the level of difficulty. Working through problems in a repetitive nature is considered rehearsing. Nick explained it as:

> [Morgan] was like, 'Okay, this is the example.' Then [Morgan would] put one on [the board] that was almost the same thing or there might have been a 2 in front of it or something like that. It's like okay, 'What do you think you do for this one?'. 'Okay, this is what you do for this part.' 'You're right. That's exactly what you're supposed to do.' [Morgan] was like, 'Well, now it's x^3. What do you think you do?'. [Morgan would] let me figure that out [before saying] 'well, actually you've got to do this …. And so, having that building instead of having the one base example and then you kind of have to figure it out for the rest of the stuff … [Morgan would say] 'this is what you're going to do for this one because of this reason, and this is why this has to go here.' [Morgan] did a very good job as far as explaining that stuff. I think that was what really made the difference because you don't have to get that in class. (Nick)

KEEPING RECORDS AND MONITORING: Because they met frequently, Morgan kept a running list of where the two of them had left off at the end of their previous session and the concepts they needed to review or still needed to cover. Monitoring their progress and keeping a record of what needed to be addressed again next time is another example of Morgan attending to Nick's needs.

Morgan modeled self-regulation strategies to help Nick get through the course material.

> There's no way that I'd be able to do well in any of my math classes, and I still didn't do very well, but there's no way I would have lasted without [Morgan's] help. (Nick)

Even after Nick completed calculus II with a C, he continued to meet with Morgan while taking calculus III, but not as frequently. "[Calculus III] wasn't nearly as bad... I just thought it was more straight forward than some of those things. Maybe the subject matter was easier too." (Nick)

Why Nick Didn't Quit or Change Majors: Personal Responsibility

When Nick applied for an ROTC scholarship, he selected engineering as his intended major. According to Luke, the students who select engineering have a better chance of being awarded the scholarship. Nick knew the Air Force was looking for people with a technical degree like engineering. Once he received the scholarship, Nick was contractually obligated to major in engineering and complete the program within 5 years. If he decided to change majors, he would lose the scholarship and possibly have had to pay back the money he already used, which Nick did not believe was an option. He was committed to finishing what he started, he needed the scholarship, was determined to join the Air Force, and wanted all of the opportunities that would come with joining the Air Force with a technical degree.

Overall Findings

This case study illustrates how, even with a poor mathematical background, a student with a clear future goal, who was able to create a path of subgoals to that future goal, and who was willing to seek out help and guidance from others when encountering obstacles was able to successfully complete an engineering degree. Understanding the importance of current tasks, in this case, needing to pass calculus II, on attaining future goals has been found to increase student motivation, performance, and persistence (Husman & Lens, 1999; Lens, Simons, & Dewitte, 2001; Simons, Vansteenkiste, Lens, & Lacante, 2004). Students who can see the connection between current tasks and future goals are more likely to stay on track (Husman & Lens, 1999; Husman & Shell, 2008). Students who begin their engineering studies in non-college level mathematics courses may need help creating goals and understanding the importance of what they are doing now and how it relates to not only their current goals, but their future goals.

While Miller and Brickman's model combining self-regulation and future time perspective has been used in multiple studies (Brickman, 1998, 2013; Brickman & Miller, 2001; Miller & Brickman, 2004; Tabachnick, 2005; Tabachnick et al., 2008), it has not been applied to undergraduate engineering students. This case study shows how this model can be adapted to explain an engineering student's commitment to his future goal and how important achieving intermediate steps, such as required courses, are to reaching that future goal. This is particularly relevant for engineering because students in a common first year engineering program cannot transfer into an engineering major until they have completed core prerequisite courses. A student starting in precalculus is typically not permitted to take engineering courses, so staying motivated and finding ways to self-regulate in non-major foundational courses is important but challenging.

Implications for Educational Practice

Part of Nick's success was strategically choosing industrial engineering as his major, which is known in advising circles and among students as one of the easier engineering disciplines (Foor & Walden, 2009). Upper division industrial engineering courses focus more on operations research, programming, and statistics than on calculus, which might be why it is perceived as being easier. In a study of over 150,000 engineering undergraduates at eleven public universities, among the five major engineering disciplines (chemical, civil, electrical, industrial, and mechanical), industrial engineering was the only discipline to have more students transfer in from other majors than transferring out (Lord, Layton, & Ohland, 2014). Students like Nick who have weak math skills can be identified early on based on their placement test scores. Advisors can recommend students with poor math skills who are determined to major in engineering to consider one of the less calculus dependent disciplines, like industrial engineering.

Nick's difficulty in calculus stemmed from poor instruction in high school, in particular in algebra I and II. Successful completion of algebra II has been found to be a measure of college readiness (Long, Iatarola, & Conger, 2009), and algebra skills have been found to predict calculus I success (Edge & Friedberg, 1984). Nick's low placement test score, which is based on students' algebra skills, placed him in a pass/fail precalculus course, and this case study revealed that Nick did not put in as much effort into the course as he might have if he received a letter grade. As educators, we can stress the importance of the course material for success in subsequent courses and help students develop strategies for retaining the required knowledge, regardless of how grades are assigned.

Through this case study, it was shown that Nick utilized several self-regulated learning strategies (Zimmerman & Martinez-Pons, 1986), including goal setting and planning, information seeking, rehearsing, and self-evaluation. However, his most influential strategy was seeking assistance when needed, which is expected of self-regulated learners (Corno, 1994; Garcia & Pintrich, 1994; Karabenick & Knapp, 1991; Newman, 1994; Pintrich, 1999; Zimmerman & Martinez-Pons, 1986). It is important that students know that it is acceptable and even expected to ask for help and how to have effective tutoring sessions that will lead to not only mastery of the current task, but long-term autonomy (Karabenick & Knapp, 1991; Newman, 1994).

Nick was fortunate in that Morgan modeled several self-regulation strategies for Nick, and did so in a way that was responsive to Nick's specific needs. Morgan directed Nick to change his environment (for example, going outside or to a classroom instead of an office) to get re-energized when Nick was having a hard time focusing. Changing the study environment is a resource management strategy Morgan used to help Nick regulate (Corno, 1994; Garcia & Pintrich, 1994; Pintrich, 1999, 2004). Morgan also helped Nick 'rehearse' calculus problems, working through multiple problems covering the same concept. Morgan continually provided Nick with feedback while they worked through problems on the board. Morgan was helping Nick plan, monitor, and evaluate his work (Pintrich, 1999; Zimmerman & Martinez-Pons, 1986). Because of Nick's poor mathematical background, he relied on Morgan to compensate for his deficits in terms of processing and self-regulating calculus tasks (Weinert, Schrader, & Helmke, 1989). Morgan, in return, provided personalized support to effectively address Nick's deficits. While personalized learning typically refers to technology-enabled asynchronous experiences (Madhaven & Lindsay, 2014), instructors and academic support personnel should be open to the benefits afforded by providing face-to-face personalized learning experiences.

Limitations

One limitation of this study is that as a case study on a single student's experience, it cannot be generalized. However, one can learn from the experiences of one of the few students who completed an engineering degree curriculum after starting in a non-college level mathematics course (Flyvbjerg, 2011; George & Bennett, 2005). There is a global need for more engineering majors (Blau, 2011; Education, 2013; Erdmann & Schumann, 2010), and it is clear mathematics is critical to engineering (Group, 2002; Levin & Wyckoff, 1988, 1995; Suresh, 2007).

Morgan's willingness to extensively help Nick over a prolonged period is a unique type of personalized support that, as Nick witnessed, is not always provided by instructors. Morgan is a faculty member in the Mathematical Sciences Department. While required to hold office hours for current students, it is not typical for instructors to hold office hours for past students, stay late in the evening or on weekends to work long hours with individual students. While this approach is admirable, it is not necessarily feasible to be replicated.

Conclusion

By studying the experience of one of the few students who began in precalculus and successfully completed a degree in industrial engineering, we were able to see the importance of future goals and self-regulation. With the help of his ROTC advisor, Nick mapped out the required courses to complete the engineering degree needed to fulfill his ROTC scholarship in a timely manner. Because he had goals set and the motivation to achieve those goals, self-regulation was triggered to help him get through the required courses.

While Nick admitted he struggled with all of the calculus courses, he really had a tough time with calculus II, having to take the course four times. Nick used several self-regulation strategies while trying to get through the course with a passing grade, but he attributes his eventual success to the personalized instruction provided by a mathematics instructor. Nick was shown by the instructor how self-regulated learning strategies such as changing his environment and rehearsing calculus problems helped him learn the material. Even though Nick entered the program with mathematical deficiencies, he had the motivation to stay with engineering, and he had the volition to seek help when needed.

This study adapted a theoretical framework by Miller and Brickman (2004) that combined future time perspective and self-regulated learning such that it is relevant for an engineering student's experience of being challenged and overcoming those challenges as he struggled through his mathematics courses. Interest was added to the model to further explain why a student chose particular future goals and proximal subgoals. Knowledge and retention was added to the framework to help explain the relationship between what a student knows from previous educational experiences, what they are learning during current educational tasks, and how it relates to their system of goals and concept of ability to achieve future goals.

Another unique contribution of this study was to provide a deeper understanding of how a student with mathematical deficiencies is able to pass the second semester calculus, a known barrier course to students seeking engineering degrees. With graduation rates so bleak for engineering students starting in lower level mathematics courses, it is imperative that these students have effective advising and have the right tools in their toolbox to complete an engineering program. This research shows that self-regulated learning strategies and mentors who model them are key for students to pass required courses.

Acknowledgement

We would like to thank the case study participants, Nick, Nick's mother, Luke, and Morgan. Nick, you are an incredible young man. Thank you for agreeing to be part of our study and for sharing your experience. Morgan, you should be commended for your dedication to helping students.

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