Students Against the Odds: First-year Engineering Students' Strategies for Improving Academic Achievement

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Introduction

This research paper utilizes qualitative methods that connect with a learning analytics' application to understand successful learning strategies of first-year students at risk of academic dismissal in a selective engineering school in Chile. The School of Engineering at the Universidad de Chile developed a model that predicts students' consecutive failings of at least one course over the first semester. This is important because failing a course twice results in dismissal. The first application of the model, which did not consider intervention at all, worked remarkably well since it had a recall of 86%, having almost no cases of false negative (error type II). However, there was a significant number of students who were false positive (error type I). These students were individuals with a high probability of failing at least one course twice but ended up passing in the second semester all the courses that they failed in the first. In this study, we sought to learn more about "false positive" students and their strategies for achieving academic success. We conducted semi-structured interviews with "false positive" students. These interviews were enhanced with a journey-map exercise[1] about these students' experiences in first year. This paper not only contributes to the understanding of academic performance in first year, but also suggests an interesting path for exploiting learning analytics tools in engineering schools, combining them with multi-method research that maximizes our opportunities for learning from both institutional data and students' experiences. In this case, we use the failure of a predictive model for learning about students who beat the odds and succeeded in first year engineering. Among the results, we identified the following themes: the positive role of family support, the importance of "being" in the School (i.e., attendance to classes, participation in extracurricular activities, and the use of study rooms), and the influence of teaching styles. For practice, the results of this study are being used for improving the predictive model, as well as the interventions associated with it.

Academic success in first year engineering

Research on academic achievement in higher education, and in first year engineering in particular, has focused on its association with dropout and retention rates[2]. This literature often discusses the impact of individual characteristics and institutional factors [1,2,3] .Scholars have also proposed multiple non-observable factors for analyzing persistence dropout and retention. Among the most influential perspectives are the dropout model of Bean and the integration process of Tinto. Bean[4], relying on studies of organizational rotation, found that intentions to leave, academic performance, and instrumental values are the most important factors in predicting dropout. With a different approach, Tinto [5], based on tribal studies, proposed that institutional integration—in the transition to college during the first year, in particular—is key to understanding persistence.

Authors who focus on engineering programs have depicted how multiple individual characteristics influence academic achievement. In particular, previous academic achievement is frequently reported as a significant predictor of academic achievement[6] However, in some engineering schools, its predictive capacity is rather modest [7]. Therefore, other factors have been closely investigated. Blumner and Richards [8] collected study habits data from first-year students at a selective engineering school. Taking into account previous academic abilities, their study showed that students with greater GPA declared more inquisitiveness (i.e., deep learning strategies) and less distractibility (i.e., low concentration when working on a task) than their less successful peers . Another venue of intense research is non-cognitive traits, which have borne mixed results. French et al. [6] found no difference between students' motivation and institutional integration and cumulative GPA. On the other hand, Vogt [9] found a positive correlation between self-efficacy and engineering students' GPA. Although attitudes towards engineering and self-confidence are not necessarily related to academic performance, they are associated with persistence[7]. Finally, scholars have also asked for the influence of race and gender. Interestingly, despite the fact women are underrepresented in engineering, they often report greater GPA than men[6]. Vogt found that women in engineering exerted more effort and were more likely to ask for academic help than men[10].

Another branch of the literature in engineering education, and STEM fields in general, has focused on the effects of teaching and the use of active learning methods on students' academic achievement. The collected evidence is strong. Freeman[11] conducted a meta-analysis of more than two hundred empirical papers in STEM education. Their study concludes that, on average, academic achievement of students who participated in active classroom had grades almost half standard deviation above the grades of those who participated in traditional classrooms. With a greater focus on the professor, Vogt [9], using a cross-institutional sample of engineering students, found that a faculty who is perceived as distant by students has a negative impact on academic confidence and on self-efficacy, which in turn influences students' GPA.

In summary, previous research has substantially shown that individual characteristics, previous academic performance, institutional factors, and other non-observable variables influence academic achievement in engineering. In the next section, we describe a model that was constructed based on the literature and on available information at the School of Engineering as an attempt to create an early warning system for first-year engineering students.

The context: A model for predicting academic failure in first-year engineering

A predictive model for academic failure in first-year engineering was developed in the School of Engineering (SoEng) at the Universidad de Chile, a public institution in Latin America. Here, we give a brief overview of the context in which this model was developed and of the methods used in its construction. A detailed explanation of the model construction and performance can be found in Celis, Moreno, Poblete, Villanueva, & Weber [12].

In Chile, SoEng is a selective academic unit, which receives students from the top 3% of the nation. SoEng has nine engineering and three science undergraduate programs, as well as a geology program, and about 4,900 undergraduate students. Each year, SoEng receives an entry cohort of approximately 750 students. All SoEng students enroll in a common core program in their first two years of school and take the same courses in the first semester: introductions to calculus, algebra, Newtonian physics, engineering, chemistry, and computing tools for engineering and science. In general, from the 750 first-year students, approximately 30% fail at least one course. In the last two decades, SoEng has implemented several strategies and actions for improving students' retention and academic performance. For instance, promoting active learning, improving infrastructure for student life, and launching specialized units to support students' academic achievement and wellbeing. Currently, first year's retention rates are close to 95%. Despite the fact this indicator is well above the national mean for STEM fields in Chile (about 65%), SoEng seeks to improve this rate, acknowledging the high quality of its student body and acknowledging that working with the 5% group that traditionally drops out in first year represents a greater challenge than those overcame in the past.

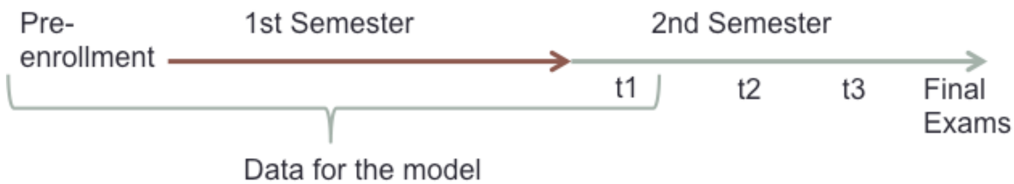
The predictive model is part of the SoEng's strategies and actions for improving students' retention and academic performance. The goal of the model was to use individual and academic records to detect student at risk of dropping out because of academic reasons. This model enabled the implementation of a system that sends early warnings of academic distress and offers intervention and support in a timely manner. For the construction of the model, we used data from five entry cohorts, from 2010 to 2014. The target, or dependent variable of the model, is whether a student fails a course of the first semester twice. This definition was important for two reasons. First, two consecutive fails in a course results in SoEng's dismissal. Even though students in dismissal can submit a special request for continuing and enrolling the course again, these requests consume considerable time of SoEng authorities. The second reason is a methodological one. Dropping out of engineering has multidimensional causes. As stated in the literature review, the most frequent causes go from financial issues to future perspectives and to academic performance. Thus, the focus on academic causes, which are not necessarily dissociated from the rest, allowed us to improve model precision. Since failing a first-semester course for the first time is a condition for failing it twice, the predictive model was estimated with a population between 195 and 255 per entry cohort.

The features, or independent variables used in the model, were selected based on the literature and information available in the Registrar and in the SoEng's course management system. Thus, we considered three kinds of variables: individual characteristics (gender and age), pre-enrollment variables (type of high school, previous experiences in higher education, national admission test scores, and high school ranking and GPA) and academic performance in first year engineering. Regarding academic performance, we created eleven variables (continues, ordinals, and dichotomous ones) based on detailed information about student grades in their first-year courses. Among these variables we included ratio of passed versus enrolled credits, variation of grades from first to second semester in both passed and failed courses, and difference between the final grade and the minimum grade for passing, which in this case is 4, where 1 is the minimum and 7 the maximum of the scale.

The decision about how much academic data to include in the model deserves some discussion. In our case, a consecutive failing can only happen in the second semester. The earlier we are able to detect those likely to fail a course twice in a row, the better. On the other hand, with more time to capture academic data, the model gains precision. Figure 1 shows the selected scenario. Thus, the model takes data from the first semester and from the first round of tests of the second semester. This definition leaves many weeks (about 75 percent of the semester or about 10 weeks) for an intervention and several future tests (usually three for each course) and the final exams in each course.

Figure 1

Timeline for the academic information included in the model



Note: t1, t2, and t3 refer to the typical first, second, and third rounds of testing in each course, respectively. Usually in SoEng, tests consist in a set of open questions or problems that students have to solve in a written manner.

Regarding the construction of the model, we used a logistic regression[13] in combination with a feature (or variable) selection technique. We selected these methods of analysis because they are relatively easy to interpret and widely used. Feature selection can be considered part of a pre-processing phase or data mining designed to select the set of features with the greatest predictive power. In our model, we used a hybrid method that combined *forward feature selection* and *backward elimination* with a cross-validation technique for selecting the variables[14]. We performed this procedure one thousand times and counted when each variable was selected. Finally, the logistic model used the variables that were selected more than 10% of the times. This procedure selected seven independent variables: gender, type of high school, and other five variables related academic performance. The variables that had more influence in the model were ratio of passed versus enrolled credits and the type of high school. Students who came from private or subsidized high schools were less likely to fail twice in a row than students coming from public high schools.

Data from the 2010-2013 entry cohorts was sed to estimate the coefficients of the logistic regression. Then, the model was used to forecast the behavior of the 2014 entry cohort. Therefore, the model computed a probability for each student who failed at least one course in the first semester of 2014. Since the dependent variable was dichotomous and the assigned probability was a continuous variable (from 0 to 1), we fixed a threshold, with which we assigned 1 to those students above the threshold and 0 to those below it. The threshold was found empirically as the point where the model's sensitivity and specificity curves intercept (i.e., where the correct classification of positive and negative cases is optimal), which in this case is a probability of 19%. The predictive power was assessed through two well-known indicators *recall* and *precision*. These indicators are defined in the equations below, where TP represents true positive, FP false positive, and FN false negative.

$$Recall = \frac{TP}{TP + FN}$$

$$Precision = \frac{TP}{TP + FP}$$

For the 2014 entry cohort, the recall was 0.86, which means that the model 86% of the times correctly classifies two consecutive failings (true positives). This result is impressive relative to previous predicting capabilities in teaching and learning contexts in higher education. On the other hand, precision was 0.38, which means the model classified incorrectly negative cases (i.e., false positive or error type I). However, this number, about 20 per cohort, is tolerable for the type of interventions (e.g., extra tutoring) and decisions that are taken based on the model. This group, the "error type I" students, is the focus of this study.

Research Question

"Error type I" students are an interesting group that offers a unique opportunity for research. The predictive model assigned them a high probability of failing a course twice during their first year. This high probability corresponds mainly to academic reasons. These students had an extremely poor performance during the first semester, where they failed two or three courses, almost always introduction to calculus or introduction to algebra. However, during the second semester, these students were able to improve their academic performance and ended up passing all the failed class. We assumed that we could learn from them. What mechanisms or strategies played a role in their academic improvement? This is important, for instance, for institutions to give more pertinent advice and support. This quest also contributes to the overall discussion about academic performance in first-year engineering. Thus, the following question summarizes the goal of this investigation:

- What strategies or mechanisms do students use in order to persist and improve their academic persistence during first-year engineering?

Method

This study used the learning analytics tool described above to conduct a qualitative study that focuses on understanding the experiences and meanings of students[15] who ended up in the error type I category of the model. We used semi-structured interviews to gather data. The fundamental question was: How would you describe you first year in "Beauchef"? Beauchef is the name of the street in which the campus' main entrances are located and how SoEng is colloquially known. The interviews also included questions about why students chose engineering as a major and SoEng as a school, how they faced and overcame difficult academic moments, and what advices they would give to new students and to the institution. The interview was also enhanced with a journey-map exercise[1] about the student experiences in first year. This technique was used to elicit students' perceptions and experiences occurred during their first year. The instruction for this drawing exercise was giving once students confirmed their participation in the interview. Their maps were the starting point of the conversations and were consulted over the interview. Each interview lasted between 30 and 45 minutes.

The sample consisted of students from the 2014 entry cohort who received from the predictive model a high probability for failing twice, but ended up passing the course at risk of consecutive failings. These students were contacted and interviewed between July and October of 2015. We focused only on the 2014 entry cohort to gather data from students with a recent first year experience. In total, we conducted 10 interviews. The interviewees consisted of 4 women and 6 men, 3 students who attended a public high school and 7 who attended a non-public high school, and 8 who came from the metropolitan region (where SoEng is located) and 2 from other regions. Students signed a consent form that ensures them no SoEng authority will have access to their identities. The names used in the analysis and in reports, including this study, are pseudonyms.

The second author conducted the interviews. She is in her last year of the industrial engineering program (in Chile, engineering programs last six years), and although she is familiar with SoEng, she transferred from another program during her third university year, so she did not experience the SoEng's first year. In short, she had a good balance between familiarity with the context and certain distance from the phenomenon. The interviews were transcribed and were analyzed and discussed in weekly meeting with the first author. The interviews were analyzed with a semi-inductive process, which considered the substantive knowledge about students' academic performance in first-year engineering, including the association between personal and institutional factors. Even though we do not claim that the experiences of the interviewees are generalizable, strong common themes emerged from the analysis.

Results

Four chronologic moments emerged from the narratives of the participant students and from their journey's maps: *Illusion, Crisis, Adjustment,* and *Self-awareness.* All interviews started with the students describing the excitement and expectation of being admitted to Beauchef, the SoEng campus at the Universidad de Chile. They talked about their preparation for the national admission test and the sense of achievement at the moment of admission. They remembered their first weeks as a moment of great expectation and satisfaction. This sense was reinforced by several activities organized by SoEng and its students for freshmen, such as the induction week to the university life. This is the moment we call *illusion.* This period ends about the end of the third week or first month, just after the first grades are communicated, when students struggle with very low grades in courses, such as introduction to calculus. This is the starting point of a slow *crisis*, whose climax is the period of exams in the first semester, when they drop some courses and experience frustration. The idea of dropping out altogether or changing major emerges. They have just two weeks of vacation to recover before the second semester starts. First-year students are required to immediately take the courses they fail during the first one. At the beginning of the second semester is when a sense of resilience emerges. Here, a period of *adjustment* starts, when these students adjust their practices, methods of study, and aspirations. Finally, students stated they learned from the failure and demonstrated to themselves that they are able to improve. They become more *self-aware* of their capabilities and aspirations as engineering students and future engineers. In the appendix, we included a journey's map (in Spanish) that represents the common paths described here. Throughout these stages, we focus on the transition from *crisis* to *adjustment,* when some events trigger key changes, what we call mechanisms, and when students define certain strategies that become successful for them. Next, we present four themes that show these mechanisms and strategies.

Family: Continuous Emotional Support and Strong Advice

For "error type I" students, the poor academic performance does not end with the first round of grades. The poor performance remains steady throughout the first semester. Thus, frustration grows and strong doubts about major choice emerge among students. Many of them think about changing major or university. For instance, Camila thought about transferring to business. Two other interviewees expressed similar intentions. Three other students mentioned changing to another less selective university. In this period, students think that perhaps engineering is not for them, and they feel discouraged and without motivation towards their subjects. They feel unsatisfied with the school. All of our interviewees declared that family support was key during this period. In particular, their parents worked as a bridge between the first and second semester. Parents gave them support all along, no matter how poor their academic results were; they always encouraged their daughters and sons. However, parents also acted in an authoritarian manner, giving strong advice about students' persistence. Parents focused on the long-run perspective and minimized the fact that the students were failing few courses. For their parents, failing and frustration were parts of the university experience. Victor's experience speaks eloquently in this regard.

> When I fell hard in all my courses, I felt frustrated, and I had two choices. One was giving up to the frustration and changing major. I thought in ecotourism. I was totally frustrated. And then I said or "I put effort and continue." **And then I was even close to drop from the School and my daddy said to me "Víctor No! Think well about it. You are giving up to the frustration."**[1] And I said to him that I wanted to change major. "I am a grown-up and can decide." And he said to me no because he knew I was frustrated. It was a source of arguments, but he made me think. It was a good move. And then I said, "okay, I will give myself an opportunity." (Víctor)[2]

As shown in Víctor's case, parents' voice and input can be strong and influence students' decision. This voice can cause arguments and conflicts. However, in retrospect, all of our interviewees viewed this attitude as beneficial. Thus, family support and advice act as an important mechanism when students face critical moments because of poor academic performance. In our case, students' families were fundamental in their persistence.

Learning to study: Finding the right method, time, and place

At some point, students decide to give themselves another opportunity, as in Víctor's case. After this decision, our interviewees reported an increase in the time and effort they put into their studies. "Learning to study" was a common phrase in the interviews. A frequent example of this learning is the realization that studying the day before examinations is not enough. Students learned to prepare in anticipation of each test. They reported a preparation that goes from 4 days to a week—In SoEng, examinations occur every week, one for each course. All of them reported a creation of academic and non-academic routines, which included schedules, places, methods, and time for recreation.

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[1] Phrases in bold represents the author's emphases

[2] Interviews were conducted and analyzed in Spanish. The interviewees' quotes presented in this study were translations done by the authors.

The most common study method is reviewing first the theoretical concepts and then solving multiple guides with problems of previous examinations. The main adjustments declared by our students go from the installation of a study-desk in their rooms to a change in class behavior, from a passive to a more proactive and engaging attitude.

Valeria failed Physics and Introduction to Calculus in her first semester. In particular, Physics represented a tough challenge since she did not have Physics in her high school. However, she substantially improved her academic performance in her second semester. “I went down a slide,” she said to communicate that her second semester was easier and smooth. This is how she summarized the reasons behind her success:

> **I learned how to study. I learned to sleep. I learned to eat. I took sport and humanity courses**. In high school, I was very much into humanities and my elective courses were related to biology. My mom sells books, so I started to read in order to recreate my self and to take a rest from so many things. In high school, I didn’t need to study. At the most, I revisited superficially the contents. Here, there were topics that I hadn’t seen in my life. I hadn’t seen Physics ever. I realized that I wasn’t good for studying in groups. **I learned how to organize my time, to organize where I studied, the book from where I studied, even my sleeping hours, and I realized that I couldn’t study at night.** (Valeria)

Valeria mentioned elements and practices that are not directly or traditionally related to engineering. She did not give up her broader interests. She attributed part of her success to an organization in many fronts of her life, from sports to readings. This self-control and time-management strategies helped her faced important challenges and learned a discipline that she never developed in high school. Valeria also learned that study groups are not effective for her. Neither was studying at night. This sort of self-discovery period was common across interviews, as well as getting into routines. However, students differed in their strategies. There was no universal practice or formula. For some interviewees, studying in groups or at night did work. While some students decided to spend more time studying at home, others decided to stay all day in the SoEng campus.

Teaching: A decisive factor

Teaching was another element mentioned by most of the interviewees. Since first-semester courses that are taught in the second semester are intended only for those who failed, class size gets smaller. A course may go from 100 students in the first semester to 60 or less students in the second. This change is felt positively. They are willing to participate more and interact with their professors. For some students, the professor made a key difference in their understanding of the subject matter.

> In the second semester, in [introduction to] algebra, I got a 5.0 [equivalent to a B] in my first test**. I was happy because I was understanding it. After that, I realized that it was a professor’s influence.** [The math professor] talked, explained and checked for understanding with questions. Then, there was a quiz, and then he explained and worked with examples. Moreover, **he made us participate in class**. He was a bit tough, he started saying, “you! Solve this problem,” and then he asked, “why did you do it this way?” He came 5 minutes before the beginning of the class and waited. Then, he built

> a barricade at the door for those arriving later. And he didn't let them in. He was a kind of wise dictator." (Ismael)

The influence of this math professor in Ismael is such that Ismael associated his improvement in grades and understanding to his teaching. Ismael also gave us a detailed description of this math professor's practices in the classroom. Interestingly, Ismael describe two features of his instructor's style that are often shown as polarized in the literature. His math professor was authoritarian and student-centered at the same time. This math instructor was strict with punctuality and had control over class participation. On the other hand, he made students participate and asked questions that made students think and engage. Often our interviewees compared their positive experience in their second semester with negative ones in the first semester. They criticized the distant and blackboard-focused instructors they had in their first semester. Student also pointed out that they did not believe instructors took into account the fact that there were some important differences regarding the academic preparation among first year students.

Self-awareness and Self-efficacy

When students reflected on their moments of crisis and how they overcame it, all of them suggested that their failures were necessary to learn important things about themselves and about their academic life. As Marta said,

> I didn't regret failing the three courses because I learned more, **because I learned a method, and because I developed frustration tolerance.** Now, I know that if I am not doing well in a course, I can salvage it later. For example, yesterday I had a test and I did badly, but then I thought, "It is just a 20% [of the final grade of the course], no more than that." (Marta)

In the case of Marta, self-awareness is reflected in discovering her frustration tolerance, a theme that was common among other interviewees. This realization is also closely related to self-efficacy, since she realized that she is able to revert a poor academic start. If she fails now, she will be able to improve later and pass the course. This resilience appeared in the narratives of many of our students. Marta's quote also suggests some gaining of perspective. A bad grade is just "20%." It does not represent the immediate failing of a course.

Recommendations and Issues of Major Choice

When it was time to talk about recommendations to the institution, nine out of ten students said at first that they did not give any recommendation at all to SoEng. They all perceived the process as something personal, not something for the institution to consider. Their emphases are on keeping the academic standards, which maybe an emphasis associated to the prestige of SoEng and to the Universidad de Chile. When they are asked a second time, they mentioned some modest suggestions, such as class size and professors' teaching quality.

An issue that strongly emerged in the interviews was major choice and the idea of becoming an engineer. However, we still need to complete the analysis in this regard, and perhaps to conduct more interviews. The evolution of students' perceptions about the engineering major is complex and well confounded with other factors. Overall, most of students came to SoEng with a vague idea of what an engineer does. The prestige of the campus and the welcoming environment of the first weeks disguise this vagueness for a while. Problems appear when they face a poor academic performance. They quickly lose motivation with their studies. Here, the "error type I" students experience a period of transformation in which they rediscover or find for the first time the allure of the engineering profession. It is here where we need further examination.

Discussion and Conclusion

Learning analytics and student learning are areas of research, which despite having a common interest in student academic success, have a rare dialog with each other. Knight et al. [16] point out learning analytics is often discontented from students' inter-subjectivity and does not take into account those who interact with the analytics tools. This study is triggered from a learning analytics application developed in an engineering school for predicting academic failure in first year. The model demonstrated a high predictive power. However, we were intrigued with those students who were wrongly classified—error type I, in particular. The model assigned to this group of students a high probability for failing a course twice in row, which results in dismissal, but they ended up passing all their courses. We sought to understand what mechanisms and strategies they followed to improve their academic performance. This study is an example of the possibilities that arise when research questions about student learning emerge alongside learning analytics developments in higher education.

Our results confirm what the literature has identified as critical factor and processes for student success. Low grades negatively impact on self-efficacy, motivation, and interest in engineering. However, when low grades came, students were able to revert their situation and show resilience. We identified four important mechanisms and strategies that facilitate this change. First and foremost, family emotional support and family authoritarian voice were part of a key mechanism for students' persistence. Here, the national culture and context matter. In Chile, as in many developing countries, universities are non residential and is common for some students to continue living at home with their parents. We can also argue that family has a predominant place in Chilean society. International comparative work in this area is needed to understand academic achievement in deferent cultural contexts.

Second, learning study habits and methods was part of this successful group of students. SoEng, as well as other institutions, have units or courses where the importance of time management and study methods are emphasized. However, the first step seems to stimulate self-awareness and then let the student explore what is more meaningful and effective for them. There is no unique recipe. Third, as said in the literature, teaching is also a crucial aspect for academic motivation and performance. In fact, in our study, active learning and small size class appeared as important factor. Nevertheless, students in our sample also suggest that a paternalistic and even authoritarian approach is also useful for them, for keeping pace and routines, such as arriving on time. Finally, our study echoes previous research in engineering education in that self-efficacy can be altered (negatively and positively) in relatively short periods of time, which has an important effect on academic achievement.

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Appendix

Marta’s journey’s map (In Spanish)