

## **Maintaining the Individual within a Climate of Indifference: Specialization vs. Standardization in the Factory Model of Engineering Education**

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## Abstract

This research paper employs data from the study of a novel *next-tier* broadening participation access program to illustrate the challenge of maintaining awareness and understanding of our students as individuals within institutional systems of assessment and record-keeping that treat all students as the same in the interests of *standardization*. These *standardized* practices are intended to aid in the production of high numbers of engineering graduates—not unlike a factory that takes in raw materials in the form of students and outputs finished goods in the shape of engineering graduates. This *factory model* of engineering education, like any high-quality mass production system, optimizes for efficiency by *standardizing* processes. In undergraduate engineering degree programs, this is apparent from the relatively inflexible *standard* curricular paths within any given major and the use of midterm and final exams as “go or no-go” measurement gauges to determine which “products” (students) are of sufficient *quality* to move onto the next step (or class) in the assembly line of curricular requirements. An important aspect of this *factory model* is that colleges are systematically *indifferent* as to which students graduate and which go elsewhere since *standardization* of the process and objective assessments are presumed to ensure fair treatment for all students.

This paper integrates findings across student performance, focus group, interview, and observational data to demonstrate the tension inherent in maintaining a broadening participation access program’s *high-touch*, personalized values within its larger institution’s methodical *indifference* towards students as individuals. This clash is exemplified through our investigation of the development and implementation of a pre-calculus course intended to support students’ progression towards “calculus readiness.” This paper describes the evolution of this pre-calculus course as its successful pilot becomes absorbed by the larger institution and expanded beyond the *high-touch* access model, with detrimental consequences for student success as the course moves from specialized to *standardized*. We propose alternative methods of preserving students as whole people within these reductionist, mechanistic environments of large-scale undergraduate engineering education.

## Introduction

The research context is a *next-tier broadening participation* program initiated in 2009 at a large research-active public university, with data collected as a part of an extensive program evaluation and assessment from 2012-16, funded in part by the National Science Foundation. Aspects of the *performance-enhancing year* program have been detailed in prior publications [1–4], thus only an overview is offered below to situate a specific *Pre-Calculus for Engineers* course that is the locus of the data and analysis presented in this paper.

The Engineering GoldShirt Program (GS) in the College of Engineering and Applied Science at the University of Colorado Boulder was founded with the goal of providing an alternative pathway to and through university engineering programs for *next-tier* students. The broader

inclusive excellence system, of which the GS Program is one component, relies on three integrated sub-models to *broaden participation* in engineering: access, performance and retention.

- *Access*: Over eight years, GS has refined its unique admissions pathway to include the targeted recruitment of underrepresented students deemed inadmissible via traditional criteria yet who demonstrate the passion, commitment, and potential to be successful engineers if given the opportunity [5–7].
- *Performance*: A GS cornerstone is the *performance-enhancing* first-year curriculum, which includes *Self-Management and Leadership*, *First-Year Engineering Projects* (design), *Engineering Explorations through Physics*, and mathematics courses. The classes are designed to immerse students in authentic engineering practices from the start of the undergraduate experience, and have evolved to feature an *asset-based, capacity-building mindset* instead of assuming that students are deficient or lacking in preparation and thus require remediation to succeed.
- *Retention*: GS includes an intentional focus on fostering learning communities and supporting students' identity development as engineers and full members of a community that cares about them as *whole* people. Multiple methods and interventions have been employed to facilitate community-building among participants, including a residential living and learning space in a prime campus location and a two-week summer bridge program with upper-class GS male and female mentors prior to the start of the academic year. The summer bridge experience culminates with GS students sharing their stories and personal backgrounds with one another, instilling the shared group value that who they are as individuals is recognized by, and matters, to the overall community.

Overall, the GoldShirt Program features a *high-touch*, systems-level focus to achieve diversity and inclusion goals, and is decidedly not a single intervention, silver-bullet approach. Yet since its inception, a major challenge for the GoldShirt Program is tension between its guiding values and practices and those of the larger institution in which it is embedded. GS strives to provide a pathway into engineering that is personalized for each student within a supportive community—a *high-touch* and asset-based pathway that recognizes and values the uniqueness of each individual. Our engineering college, in contrast, operates according to what might be described as a *factory model* that aims to produce a high number of engineering graduates annually, and for efficiency's sake, is largely *indifferent* to individual student needs.

This paper examines the clash between the *high-touch* GoldShirt system model and the institutionalized *factory model* prevalent in engineering education in the context of the development and implementation of a pre-calculus course. Since math is a critical gateway, or bottleneck, that all engineering students must pass through to reach subsequent levels of major-specific technical coursework, pre-calculus success is a vital component of the *performance* sub-model of the inclusive excellence GS Program. In curricular structure and cultural practices, math progression identifies a student's position along the trajectory towards becoming an engineer, so success or failure in mathematics courses has significant consequences for student feelings about belonging in engineering and ultimately retention in engineering majors. Our paper examines how to preserve the focus on students as whole people within the reductive,

mechanistic systems of assessment and institutional record-keeping—including placement tests, midterms, and overall grading—which simplistically relegate individuals into single numbers to represent students' learning, preparation or even worthiness for continuing in engineering.

### **Background: Cultural Production in the Factory Model of Engineering Education**

Educational researchers across the fields of sociology, anthropology, psychology, and history have demonstrated across a variety of ages and locations the ways schools serve to *produce* and define a certain type of person deemed a “good student.” For example, Packer and Greco-Brooks explain how from the very first day of first grade in American schools, rules are introduced to organize the activities of those present based on a new set of relationships between “teacher” and “student”—identities that become salient through students' desires for “recognition” and “belonging” within the classroom. The authors convincingly illustrate the work of *cultural production* that begins from the start of elementary school, ultimately finding that the distinction between “good student” and “bad student” is “less a matter of correct and incorrect answers than it is of proper and improper deportment” [8]. This means that students are learning not just academic facts and concepts, but also how to align their behavior with the institution's expectations and rules in order to be considered “good” or “successful.” In this way, school is a site for producing patterns of activity and identities that satisfy desired cultural values.

The work of Levinson and Holland [9] further explores the concept of the *cultural production of the educated person* in-depth through a variety of studies across a spectrum of cultures and times, describing how the “products” of educational systems are closely related to the “historical and cultural peculiarities” in which they are embedded. The well-known work of Willis [10] illustrates how qualitative, ethnographic research methods led to an expanded understanding of how the British working-class “lads” studied were active agents resisting the middle-class ideologies of their schools, not passive subjects the schools socialized into their working-class futures. Yet in struggling against the rules of school and choosing not to participate in “good student” behaviors, the lads were ultimately complicit in *reproducing* the social order and maintaining their working-class status. Thus Levinson and Holland situate the notion of the “educated person” as a cultural construction “within, outside, and against dominant, elite- and state-sponsored institutions,” demonstrating that our understandings of “education” are always negotiated [9]. From this, we consider it critical as educational researchers to consider from where our concepts and definitions of “education” derive, and who decides what constitutes an educated person and successful student within our specific contexts. Without this awareness, we are simply *reproducing* dominant cultural models that define success and failure without challenging their accuracy or relevance to our students and our unique situation as researchers of engineering education and engineering culture.

Within an engineering context, the work of Downey [11] expertly demonstrates how the definitions of successful “engineering education” have dramatically shifted over four distinct episodes in the course of American history since the 19<sup>th</sup> century. In connecting political agendas and the rhetoric surrounding “American progress” to changing meanings of what constitutes engineering and engineering education, it is apparent that the “products” of engineering institutions have been deemed successful upon their “fit” into advancing either American industrial or research agendas—all in the name of progress. For example, the current model for

engineering education stems from the national agenda to win the Cold War [12] while maintaining domestic comfort by protecting “private production and consumption” through the creation of a new type of engineering industry, the “defense contractor.” Moreover, Downey convincingly explains how the dominant theme of “low cost, mass use” has governed interpretations of success in American society and in the production of engineers, as the middle-class model for self-realization via consumption requires a significant output of standardized engineering graduates as products to sustain the “American way of life.” Thus, our current measure of the success of an engineering school is defined by how efficiently, and in what quantity, its graduates satisfy the standards established by engineering industry, engineering research agendas/graduate schools, and national defense agencies.

Overall, these theories of *cultural production* enable us to see schools as factories, producing a certain type of person deemed a good student or an “educated” individual. Engineering schools, specifically, produce a certain categorization of an educated person—a successful engineering graduate—in mass quantities as needed to support the development, growth, and consumption demands of the nation and beyond. Throughout this production process, gauges of success and failure known as “tests” or “exams” serve as ostensibly objective gateways to measure how well schools are satisfying production targets, in both number and quality. While a great deal of scholarship calls into question our reliance on these standardized testing measures [13, 14], our focus in this paper is to contrast how our *high-touch, broadening participation* GS Program exists in spite of (and in conjunction with) the ongoing large-scale *production* processes of our engineering college. In this paper, we investigate the recent development and implementation of a *Pre-Calculus for Engineers* course, specifically analyzing the challenges of sustaining an inclusive excellence culture and program within the limited definitions of success and failure, education and “engineer” as expressed through the standardized pathways and gauges that assign evaluative labels to students moving through the undergraduate engineering degree pathway.

### **Background: Research Setting and Course Structure**

At the outset of the GS Program, students whose initial math placement indicated they were not ready for *Calculus 1 for Engineers* (Calc 1) had only one option: take MATH 1011: *College Algebra*, offered university-wide for a broad audience of mostly non-engineering students. Yet GS students who successfully completed MATH 1011 subsequently performed poorly in the engineering college’s Calc 1—many failing. In hindsight, students attributed their subpar Calc 1 performance to the lack of motivation and bad habits they picked up while “repeating” the perceived high school level, remedial math of *College Algebra*.

Seeking an engineering-focused option, GS Program and the Department of Applied Math (APPM) leaders agreed to develop a *Pre-Calculus for Engineers* (Pre-Calc) course specifically targeting preparation for the subsequent engineering calculus sequence. An experienced calculus instructor, Sara, was recruited from a community college because of her success in preparing students, many from backgrounds similar to those of the GS students, for calculus. The GS Program’s initial Pre-Calc offering was successful. The overwhelming majority of students met stringent requirements (grade of B- or better) for moving into the calculus sequence after one semester; most of those who did not initially achieve a B- or better grade did so the following semester after taking a second, small, seminar-like offering of Pre-Calc taught by the same

highly regarded instructor. Both students and instructor attributed this high rate of success to the *high-touch* structure and high accountability of the course, which targeted individual students' strengths and struggles. One student, who initially did not pass the course but did so the second semester, was subsequently invited by Sara (on the basis of their close work together) to serve as a "learning assistant" (LA) for the course the following year—a position that recognized her developing math abilities and cemented her positive view of her own capabilities [15].

Multiple interviews with Sara confirmed how she not only fundamentally believes in her students' capacity for hard work and success, but she also personally cares for them:

"I love these kids, you know... the majority of them, they deserve the chance to make it. That's what I love about this program, the GoldShirt Program I'm talking about. I mean the whole Pre-Calculus class is fantastic too, but this GoldShirt cohort, they're so tight and like I've handpicked my LAs. Of the six we have, five of them are GoldShirt students."

~Sara interview excerpt #1

Sara is quick to credit the students for their learning—an important theme for her class. She recognizes hard work and successful mastery of the content. Employing multiple GS students to serve as LAs in subsequent semesters is another way Sara shows her students that their success is valued and seen by the overall community. It also demonstrates that Sara is committed to GS students and supports their development beyond the boundaries of her class.

Even further, Sara attributes the GS student success in her Pre-Calc class to the students' actions, not her pedagogy or teaching style:

"They [GS Program administrators] saw great success with that class and I think they thought I had a lot to do with that, but I think they were just a great group of students. So what's been communicated to me is that she [GS Program director] thinks it's me and she wants her students with me. I mean, but I really think it was a great group of students and they worked really hard."

~Sara interview excerpt #2

By deflecting the praise for her students' success back onto the students' own hard work and efforts, Sara is reinforcing the GS Program value that all students have ownership over their own capacity for success, provided they work at it, take advantage of the available resources and persevere through challenges. In hiring GS students as course LAs, Sara legitimizes their identities as *experts* in the classroom and valued members of the academic community. So through her actions and words, she provides an alternate definition of *success* and *education* than what is expressed in the mainstream production pathways of the engineering college.

However, the success of Sara's pilot sections of Pre-Calc led to the loss of these *high-touch* and *asset-based* characteristics when the engineering college moved to significantly and rapidly increase the number of Pre-Calc sections to serve engineering and pre-engineering students more generally, beyond the needs of the GS Program. In Fall 2013, oversight of the *Pre-Calculus for Engineers* course was taken over by the Department of Applied Math and expanded to 10

sections taught by six different instructors with varying experience levels and orientations toward pedagogy and student success. Whereas 29 GS students composed the Pre-Calc course in Fall 2012, just one year later 243 students took Pre-Calc—a 700%+ enrollment increase! The course “ownership” also changed from general engineering (GEEN 1235) to Applied Math (APPM 1235)—with its adoption into a different department’s course offerings and culture.

Prior publications stemming from the overarching research project have explored the impact of math placement tests on student success through the mathematics curriculum [16], the initial success of the *Pre-Calculus for Engineers* course for GS students [17], and the negotiated and contested process through which students are assigned the milestone status of being “ready for calculus” as a result of this course [18]. This paper adds to the overall body of knowledge by examining the transition process and scaling-up of the *Pre-Calculus for Engineers* course, explaining via both qualitative and quantitative data what is lost and gained when a *high-touch* model for engineering education becomes incorporated into the larger structural *production* mechanisms of a public state research-active university.

## Methods

As mentioned in the Introduction section, this paper employs a subset of data from a comprehensive program evaluation and assessment project spanning four years. Both quantitative and qualitative in overall scope, this analysis focuses on qualitative interviews, focus groups, and observational data to describe the consequences of losing a *high-touch* focus within a prevailing climate of impersonal standardization. Quantitative data in the form of student enrollments and course performance over multiple semesters of Pre-Calc are also employed to numerically illustrate the impact of moving from a small-scale, specialized course offering to the large-scale, assembly line model.

An overall tally of the entire qualitative dataset collected as part of the overarching study from which this paper draws is provided in the Appendix. A broad sampling approach was used throughout the qualitative data collection process over multiple years; students, program administrators and faculty were interviewed, observed and convened multiple times for focus groups, facilitated by qualitative researchers from a variety of disciplinary backgrounds. In conducting such large-scale data collection, attention was given to maintaining focus on each participant as a whole person with a unique trajectory and development while simultaneously working to identify emergent themes and similarities across the stories told, attempting to satisfy basic requirements for *procedural* and *ethical validation* [19]. Table 1 includes a subset listing of the qualitative data sources analyzed to reach the findings presented.

Table 1. Subset listing of qualitative data used in this paper.

Semester / Activity	Type of Qualitative Data	Duration (approximate)	Number /Type of Participants	How Data Used for Paper
Fall 2014: Pre-Calc Class Sessions	Video of classroom observations	7 class sessions of 50 min each	Students in class + LA + Instructor	Indirectly (see [20] for analysis)
Fall 2014: Pre-Calc Instructor Meetings	Video of instructor meetings	5 meetings of ~60 min each	Instructors	Indirectly (see [20] for analysis)
Fall 2014: Grading Sessions	Video of grading sessions	2 grading sessions (1 midterm + 1 final exam), ~5 hours each	Instructors + TAs	Indirectly (see [20] for analysis)
Fall 2013 and Spring 2014	1x1 interviews with instructors and GS staff	6 interviews; ranging 30 min to 90 min in duration	Pre-Calc Instructors and GS staff	Directly
Fall 2013, Spring 2014, Fall 2014: Student Interviews	1x1 interviews with GS students	13 interviews; ranging from 40 min to 90 min in duration	GS students	Directly
Spring 2016	1x1 interviews with students in Pre-Calc	11 interviews; ~60 min each	Students enrolled in Pre-Calc currently or in prior semester (GS and non-GS)	Directly

All quantitative and qualitative data collection included procedures for participant recruitment, data management, processing, analysis and reporting as approved by the Institutional Review Board at the study site. Qualitative data—including focus groups, individual student interviews, individual faculty interviews, and extensive classroom observations—were video- or audiotaped and later transcribed. To protect participant identities and ensure overall *process reliability* [19], pseudonyms were assigned and personally identifying details were removed as necessary.

*Qualitative Data Analysis Procedures Addressing Threats to Interpretive Validity:* The qualitative data analysis team for the dataset presented in this paper included three individuals with unique levels of involvement in the project: 1) an education doctoral student who conducted many of the interviews and focus groups, 2) a co-principal investigator who oversaw all aspects of qualitative data collection and analysis, and 3) an engineering education post-doctoral researcher who became involved with the project after the bulk of qualitative data was collected. During the fourth year of the NSF-funded research project, the qualitative researcher team met weekly to discuss emergent themes in the data and compare results of open coding in the qualitative data analysis software package Dedoose [21]. In addition to open coding, the research team employed interpretive techniques—including discourse and narrative analysis of exemplar passages—to further support and reveal meaning in the data.

Themes that rose to prominence, including the concept of maintaining the *high-touch* GoldShirt program focus within the factory model of engineering education, were subsequently discussed with the entire research team during monthly project meetings. These sessions convened the principal investigator, other co-PIs, and quantitative researchers to determine relevance of emerging themes and debate data interpretations across the varied perspectives of the team.

Connections to theoretical constructs, including *cultural production*, were discussed and challenged in light of the research team's personal experiences and the data as a process of *theoretical and pragmatic validation* [19]. Quantitative data—including student test scores, grades, and survey results—were often brought into the research team's discussions to corroborate and contest the emerging qualitative data findings. In this way, the qualitative research team's process of eliciting meaning from the data was continually checked against other potential research interpretations to practice *communicative validation*. This ensured the interpretations generated were well-understood and sensible across the multiple communication communities involved in the research and administration of the GS Program [19].

This paper describes the evolution of the Pre-Calc course as it was absorbed by the larger institution and expanded beyond the *high-touch* GS access model—with detrimental consequences for student success as the course evolved from specialized to *standardized*. We address three main research questions:

1. What is lost when we reduce students into numbers at various levels necessitated by institutional record- and gate-keeping?
2. What are the consequences of losing *high-touch* as a core value in inclusive excellence programs?
3. How can academic and support programs instill a high-touch mindset within an efficiency-focused factory environment of growth-prompted standardization?

## **Findings**

*Quantitative Student Performance over Time in Pre-Calculus for Engineers:* As the *Pre-Calculus for Engineers* class was integrated into the formal course offerings of the Department of Applied Math and expanded to serve pre-engineering and engineering student needs beyond the GS Program, we ascertained that the average final course grade (GPA) began dropping at an alarming rate (from 2.71 to 1.86 three years later) in tandem with its radical enrollment growth (see Figure 1).

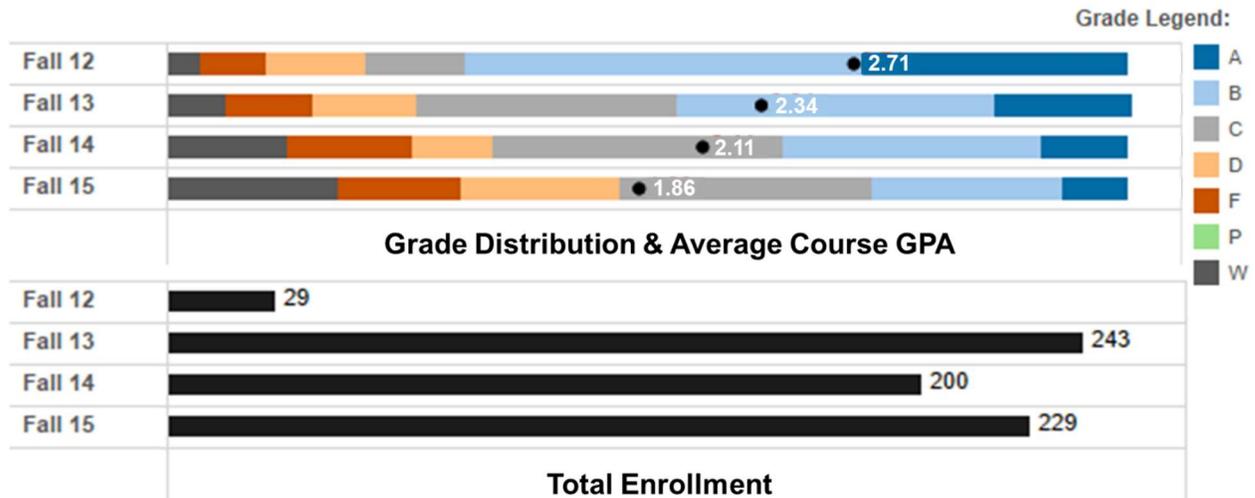


Figure 1. Enrollment, grade distributions and average grades in *Pre-Calculus for Engineers*.

This quantitative performance data indicates a disheartening trend: a precipitous drop in average course GPA across four semesters of course offerings, coupled with significant increases in numbers of students earning grades of C, D, and F or choosing to withdraw (W) from the class rather than take a hit to their grade point averages. This data illustrates an institutional and programmatic contradiction: despite the intention to better prepare students for the follow-on *Calculus I* course, fewer and fewer GS students were achieving high enough grades in Pre-Calc to be granted the status of being “calculus-ready.” Previously, the Pre-Calc course was lauded for successfully preparing students along the undergraduate mathematics pathway [17] and was considered crucial to the college’s strategic plan to broaden participation in engineering. This change motivated the research team to investigate what was happening to students within this course.

*Qualitative Investigation: What Happened to Pre-Calc?* In spring 2016, 11 interviews with engineering students who had taken Pre-Calc one or more times were conducted to enable the research team to peer into the students’ experiences in the course. Interview participants were students who had recently taken (or re-taken) the scaled-up version of the course, including students both in and outside of the GS Program. This expanded student population enabled researchers to delve into differences in student perceptions and experiences in the class.

We start by examining portions of our interview with Drea, a highly articulate GS student who withdrew from Pre-Calc in her first semester and was re-taking it during the interview. She explains:

“Last semester, I was like, ‘I took it [Pre-Calc] in high school. I can do this.’ Then, the first exam came and there goes my ego right out the window. That definitely tore me down that this is actually completely new material that I’ve not learned before. The exams are way harder than they teach you in class. In class they teach you the fundamentals of the system. On the exam, they expect you to grow on those fundamentals by that point. That’s something I was not prepared for, cause in high

school they test you on the fundamentals. Then, so the homework is the same as the exam.”

~ Drea, first-year GS student

Drea traces her initial poor performance in Pre-Calc to two distinct factors—1) her ego, which led her to believe that since she had completed Pre-Calc in high school she would be well-prepared for success in the college course; and 2) the difficult nature of the first Pre-Calc exam. While the entire GS first-year curriculum is intended to support students’ identity development as engineers and students with the capacity for success in engineering college, we see from Drea’s experience that confidence in one’s abilities to succeed in engineering courses can be easily “torn down” by the first encounter with a challenging math midterm. That she connects her “ego” going “right out the window” after this experience suggests that the *high-touch* aspects of the GS Program are not enough to maintain this image of students as having the ability to succeed when faced with “completely new material” on exams that are “way harder” than what is taught in class.

Despite the previously successful, handpicked instructor (Sara) continuing to teach Drea (and two sections of Pre-Calc), our qualitative analysis showed a marked shift in the nature of the course as it increased in size to 10 sections taught by six faculty—especially with respect to identifying which students were deemed to be “calculus-ready.” Demands of scale, objectivity, and fairness across sections fundamentally changed the way in which student work was graded. Rather than careful oversight of students’ work by a single instructor, exams were graded *assembly line* fashion by all instructors and teaching assistants. Each grader was responsible for a specific exam question in isolation from the rest of a student’s exam and without awareness of a student’s other efforts in the class. Related to this, “calculus readiness” became defined not in terms of a holistic understanding of a particular student’s work, but in terms of how students’ aggregate *scores* related to those of other students and to an impersonally determined minimum score, without attention to any differences in the experience and instructor styles. Thus, unfortunately, the *scaling up* of the Pre-Calc course absorbed it into the prevailing *factory model* of teaching and learning that characterizes Applied Math—and engineering and higher education more generally—largely eliminating the *high-touch* GoldShirt characteristics that had led to the course’s initial success for underrepresented, *next-tier* GS students. Whereas Pre-Calc was initially developed as a key element of the *performance-enhancing* first-year of the GS Program under an asset-based, capacity-building mindset, as the course increased in size, these aspects were lost as a byproduct of moving towards greater “efficiency” as necessitated by the factory model’s scale demands.

Drea goes onto explain the thought process behind her choice to withdraw from Pre-Calc her first semester:

*Interviewer:* “What was the reason people said to withdraw the class?”

*Drea:* “Because of that B- [grade] requirement. Then they know they couldn’t [reach] it. I have a friend now who got a 79.7 in the class, or something, and he was super upset. He’s retaking it. I think that was the point where everyone knew that if I can’t get that requirement, I might as well drop it now instead of pulling

through and getting that on my transcript... In the [GS] program, they always say to start with a high GPA because it's gonna go lower over time. Those classes get super hard."

~ Drea, first-year GS student

Here, Drea explains the dominant messaging as interpreted by GS students who are on the cusp of achieving the minimum B- grade, which officially signifies "calculus readiness" and structurally enables progression through the engineering curriculum. Her friend who is just 0.3 points away from the cut-off is nonetheless still below the cut-off, as the *standardization* of policies in Pre-Calc means a lack of exceptions or flexibility to accommodate individual student circumstances. Drea notes that her friend is "super upset" and "retaking" the class, an understandable emotional response to a rigid system whose definitions for success and failure are non-negotiable. Prior analyses of the grading processes in this Pre-Calc course revealed the subjective and hidden steps in which overall class grade distributions are examined by instructional staff to create the "curve," which ultimately determines students' final letter grades in the course [22]. This single letter grade is the main artifact recognized by official record-keepers as a meaningful representation of what a student learned in the course; thus, it serves as the marker of a student's worthiness of proceeding in engineering mathematics or repeating the course once more.

Students like Drea who opt to withdraw from the class instead of being permanently marked with a low grade are partially circumventing the narrow definitions for success and failure in engineering school, since her institutional transcript reads W instead of a C, D or F. Yet she is also reminiscent of the working-class British "lads" studied by Willis who ended up actively *reproducing* the social order even as they resisted against the norms and expectations of formal schooling [10]. GS students who proactively withdraw from these courses face a quandary; they are choosing to resist being institutionally labeled as poor performers with low GPAs, yet must overcome being behind in engineering coursework, needing to re-take Pre-Calc and eventually pass the course if they want to make sufficient progress in their engineering degree programs.

Drea's statement also explains a systematic strategy for GS students navigating the impersonal *factory* of the engineering curriculum—that one must "start with a high GPA" and assume that it will drop "over time," as "classes get super hard" and the higher you start, the more cushioning that exists to absorb poor individual class grades. Given the *indifference* of the GPA system in determining success or failure of individual students moving through the curriculum, this strategy makes sense; the academic suspension and probation cut-offs are rigid and cannot easily be adjusted for individual circumstances. The scheme to start with as high a GPA as possible because of the assumption that the process of moving through engineering coursework will cause this assigned number to gradually fall, illustrates a casual acceptance of an individual's *relative powerlessness* to negotiate rules or definitions of success within a mechanistic, monolithic system of record-keeping maintained by the engineering college.

Contrast Drea's strategy for getting through the impersonal engineering curriculum with the perspective of the instructor, Sara, presented above as part of the background and research setting. Recall that Sara believes that the GS students "deserve the chance to make it" and that they are a "great group of students" who "worked really hard." While Sara describes the students

as people, recognizing their efforts and potential for success, this sense of personal empathy is missing from Drea's explanations of how she has adapted to the indifferent labeling mechanisms (including GPAs) used by the engineering college to sort students into different levels of curricular progress. How do we reconcile these two disparate views of how students exist and move through this *factory* of engineering education?

Another account of Pre-Calc from a non-GS pre-engineering student corroborates this perception of the engineering college as impersonal and indifferent to individual students:

“I think Pre-Calc is a huge weed-out class. I think they do that because it's pre-calc, so you're already behind, like I said. They're thinking, 'These kids want to go into engineering, but they might not be suited for that profession. We're gonna do this as a weed-out class. If they do that, then—and they never get to calculus they can't take all these other calculus [-based courses]. They're already out of it.' They don't have to worry about these kids coming in and not being able to do these higher level classes. Once you're in calc, though, a lot of people feel that... once they get there then oh, they've proven themselves. They can be an engineer. Now they can take these other classes and be on their way.”

~ Liza, *first-year pre-engineering student*

Liza attributes the desire to make Pre-Calc a “weed-out” class to the wishes of an omniscient “they” entity, ostensibly the operators of the engineering college who are in charge of defining and determining who “can be an engineer” and who “might not be suited for that profession.” Missing from her explanation is acknowledgement of her own ability to take action in this system, as she is focused on what “they” are thinking in “doing” Pre-Calc as a “weed-out class.” Whereas Drea at least had a strategy and options that she could employ in working with this impersonal *factory model* of engineering education, Liza's words are passive; she has no particular plan or action to respond to being classified as “already behind” or “already out of it” simply because she is enrolled in Pre-Calc.

Simultaneously, qualitative interviews and observations of the Pre-Calc faculty revealed that the purpose of increasing the complexity of the course while massively scaling it up in enrollment was to prepare students for the *rigor* of the engineering calculus sequence. Upon official adoption into the Applied Math sequence, the course shifted from ensuring that foundational algebra concepts were well-understood to providing additional engineering context to problems, in the hopes that this would motivate the content more effectively for Pre-Calc students. Just prior to the start of the Fall 2014 semester, Sara explains:

“One thing we [Pre-Calc instructors] are trying to do is new to this semester, we're trying to motivate the next idea with an engineering application. And it's really hard for this first chapter, it's so basic that it's kind of hard, but for example we're teaching piecewise functions and there's a model for the wind speed of a hurricane... So we're trying to put some nice applications in there and it's modeled with a piecewise function. So that's our new goal this fall to start out each chapter with a nice—that's not so much engineering, we couldn't really find something—but we're hoping especially with exponential functions to do some nice, maybe Newton's law of

cooling or some circuit analysis where we can have a nice application of an exponential function and then go into the discussion of exponential functions because I guess we really want them to, hopefully engage them, but buy into why they really need this.”

~Sara interview excerpt #3

In discussing how the Pre-Calc course was changed for the upcoming semester to include more engineering applications, Sara repeatedly uses the pronoun “we” to describe the actions, beliefs, and hopes of the instructional team. In the interview excerpts presented previously, in the background section above, Sara repeatedly uses “I” to describe her own perspectives on how the GS students are deserving of a chance, how she loves the students and the program, and how she attributes the students’ success to their own hard work and efforts spent learning the material. Excerpted from the same interview, it is striking how Sara switches perspectives. Instead of reflecting on how she individually ran and controlled the course in the past, she is describing how “we,” the larger group of Pre-Calc instructors, plan to administer the course in the future. Now she speaks for the group instead of herself, a group whose collective “new goal” is to incorporate some “nice applications” to “hopefully engage” the students as well as get them to “buy into why they really need this” [content]. In the past, less concern existed about getting students engaged or convinced of the necessity of the course content since it was small, personalized, and successful. A byproduct of the course scale-up is the need to justify to a broader audience of engineering and pre-engineering students, both in GS and not, of the usefulness and importance of this course to their futures as engineers.

Sara continues:

“I try to drive home why we need these skills for when they are going to calculus. So that's the reason we want to have some engineering applications to help them sink their teeth into it and they want to be engineers, so we're hoping that'll excite them, but also we want to motivate why they need these skills for calculus. Because, of course they're not thrilled they are in a class that is below where they need to be starting.”

~Sara interview excerpt #4

The first sentence of this excerpt illustrates Sara’s unique positioning with the students as well as the instructional team. She exists as an individual, “I,” yet is part of the collective “we” of the instructional group who “needs these skills” to be well developed for “they,” the students who proceed to calculus. This shows that the focus has shifted from equipping students for success in engineering via solidifying foundational algebraic and trigonometric concepts to equipping the students to succeed *in the Applied Math sequence*—a small but meaningful difference that indicates a shift in the characteristics of the student *products* being output from the Pre-Calc course. Previously, the *production processes* of Pre-Calc were specialized and individually tuned by Sara to ensure quality in the form of conceptual understanding. Going forward, the class is optimized around preparation for the subsequent calculus courses, which includes not just conceptual understanding but also experience with the patterns of behavior, expectations, and activities typical of the Applied Math environment. This effectively changes the definition of a successful student to be in line with the mechanistic, impersonal tendencies of the mathematics

program instead of the *high-touch* GS Program. The “they” entity Sara speaks for is similar to the all-powerful “they” that Liza refers to in her statements above. “They” control the levers in the form of letter grades that sort students into passing/failing Pre-Calc and moving forward/being stalled in the engineering undergraduate pathway.

This perspective shift is further reflected in Sara’s statement that Pre-Calc students are “not thrilled” to be in a course “below where they need to be starting,” which is a surprisingly deficit-based statement about where the Pre-Calc students are in relation to their peers who are apparently *superior* by virtue of their initial positions (*Calculus I* or beyond) in the math sequence. Sara’s words partially confirm Liza’s belief, presented above, that Pre-Calc is a “weed-out” class designed to filter out those who are not worthy of proceeding through the engineering math curriculum and in conjunction, engineering degrees. Again, this is incongruous with the initial goals of the GS Program and with Sara’s belief expressed in the first interview excerpt that all of the GS students “deserve a chance to make it.” While motivated by a seemingly straightforward desire to “excite” the engineering students, providing additional engineering applications, complexity and context to the course has the added consequence of further aligning Pre-Calc with the prevailing *factory model* of the engineering college.

We share these seemingly incongruous sections from Sara’s interview not to vilify her or diminish her outstanding teaching skills (as evidenced by her sections’ higher grades compared to her colleagues’ over many semesters), but rather to illustrate that instructors as well as students can easily become purveyors of the norms, patterns of behavior and activities of the *factory model* of engineering education. Sara is a gifted instructor who truly cares about her students. These excerpts show that even an excellent faculty member may not be able to resist being incorporated into the ongoing mechanisms of our engineering college, whose standard operating procedures serve to reliably *produce* a specific type of engineering graduate while sifting out those who do not fit the mold.

## Discussion

Moving forward in time, the results of adding more engineering context to Pre-Calc after the Fall 2014 semester include lower overall grades earned by students (Figure 1) and the feelings of powerlessness expressed by Drea and Liza in their interviews. Coupled with lackluster student performance data across the spectrum of mathematics courses in the engineering college, our institution was convinced to assemble a “task force” to re-evaluate the direction of the overall math curriculum, with most attention given to *Calculus I* and *II*.

Separately, the GoldShirt team, including instructors and administrators, convened a group to focus on the *Pre-Calculus for Engineers* course—re-examining it and re-establishing its purpose to equip all students with the preparation, practice and skills to be successful in the engineering calculus sequence, even at the cost of providing less engineering context to problems. Included in these discussions was debate about the rigor appropriate for the course, while acknowledging the *high-touch* intentions and values of the GoldShirt Program. Separate from the college-wide task force, this GoldShirt group reinforced its belief that the purpose of Pre-Calc is indeed to prepare *all* students for success in calculus rather than weeding out students who do not prove

themselves to be “calculus-ready” and subsequently worthy of proceeding through the engineering curriculum.

Our first research question asks, “What is lost when we reduce our students into numbers at various levels necessitated by institutional record-and gate-keeping?” As shown through the qualitative data excerpts presented in the Findings section, we lose a sense of our students as whole people and unfortunately, students can easily lose their understanding of their personal abilities *as learners* when they feel *powerless* in the face of a monolithic *factory model* of education that appears *indifferent* to their individual struggles and successes. As Drea described the loss of her ego in the aftermath of the first Pre-Calc exam and the resulting navigational strategy of withdrawing from the course to protect her GPA, we see that students like Drea learn to optimize their behaviors and actions to succeed given the inflexible *standards* of the engineering curriculum. Similarly, Liza explained why she believed Pre-Calc was a “weed-out” class, a *mechanistic* gauge to sort and separate out those who could make it in engineering from those who could not. Recalling how the College of Engineering is *producing* engineers, from Drea and Liza we note that this *production* process relies on students who adapt and accept the *standard* practices of strategically optimizing one’s GPA and subordinating one’s personal experience to the overall labels of success or failure as assigned by the impersonal “they” in charge of these designations. Likewise, instructor Sara undergoes a related process when her personal beliefs about the capacity of all of her students to succeed are overtaken as she is subsumed by the values and expectations of the Applied Math culture. This is in direct contrast to the aim of the GoldShirt Program to recognize and respect students (and staff and faculty) for the unique and individual experiences, perspectives and beliefs they bring to the College of Engineering. Another apparent casualty of becoming a successful *product* of the Pre-Calc course, a requisite step along the assembly line to ultimately becoming an engineering graduate, is this apparent loss of self, or a sublimation of one’s individuality into acceptance of fitting in and being officially recognized as “ready for calculus.”

Our second research question asks, “What are the consequences of losing *high-touch* as a core value in inclusive excellence programs?” The quantitative performance data illustrating the precipitous drop in average final Pre-Calc grades over time compellingly shows one severe consequence of the *high-touch* model of Pre-Calc instruction being absorbed into the *standard* processes of the engineering college—higher withdraw rates and yet still lower overall course grades. Those outcomes do not help to accomplish the *broadening participation* goals of the GoldShirt Program or the larger institution that envelops it. Furthermore, as described above, the loss of individual control and personal beliefs is another consequence of letting go of *high-touch* values while moving instead towards greater alignment with the *production processes* already at work in the engineering college. Even with instructors like Sara and others in GS who may wish to maintain a focus on the individual and understand the importance of seeing students as whole people with the potential for significant achievements, maintaining these beliefs within the broader mass production environment is near impossible.

Our final research question asks, “How can academic and support programs instill a *high-touch* mindset within an efficiency focused factory environment of growth-fueled standardization?” Clearly, the answer to this question is not simple. Work continues to understand how to maintain the *high-touch* aspects of GS while also enabling GS students to proceed smoothly through the

*standard* engineering curriculum and the Applied Math calculus sequence. Years of investigation into this question have yielded greater awareness of our tendencies to *reproduce* elements of the indifferent system of engineering education that GS actively intends to disrupt. We note that consistent monitoring is required to keep the *institutional crucible* from boiling away the impact of personal attention and caring that enables *high-touch broadening participation* programs like the GoldShirt Program to succeed, even within the mechanistic pathways of large engineering colleges.

## Conclusions

We interpret the difficulties encountered in “scaling up” the Pre-Calc course as an example of the tensions faced by any *high-touch broadening participation* program that must coexist within an institutional framework that necessitates reducing students into representative numbers like exam scores and GPAs for tracking and placement within the system. While the GoldShirt Program aims to recognize students for their whole selves, including their unique life experiences and unquantifiable personality traits, this is fundamentally at odds with institutional systems that rely on decomposing individuals into numbers and letters that appear on transcripts and spreadsheets so as to be more easily compared and transported through the official avenues that denote progress through undergraduate engineering degree programs. This reduction of students into numbers happens on every scale—from grading individual homework assignments and exam questions, to adjusting final course grades, to assessing entire courses and degree programs.

As researchers on this project, we have identified many ways in which our own processes of record-keeping, tracking, and eliciting meaning from individual students’ experiences often rely on reducing these students into encapsulations of their lives that can, by definition, not represent the richness of their full, lived experiences. We note through critical reflection that the onus is on us as well as the administrators, faculty, and *factory* leaders of the engineering college to maintain vigilance and awareness in how we can view our students as whole people even as we condense their selves into interview excerpts or data points for publication. While we use traditional metrics of GPAs and exam grades to mark how successfully or unsuccessfully students move through the impersonal systems of engineering education, we must do so with caution and with an eye on how this reduction comes at the cost of adopting the mechanistic framework that has *produced* a certain type of engineer over the past five decades in the U.S.

Our institution’s math “task force” has discussed what structural changes might enable improvement in student outcomes related to the Applied Math curriculum, resulting in several new initiatives that will be implemented for the Fall 2017 student cohort. The incoming mathematics placement process was radically revised using student entry variables that include both cognitive and non-cognitive measures to aid in more optimal placement of students into the appropriate level of math course as they begin their undergraduate careers. In addition, the Wright State Model of *engineering mathematics* will be piloted as a standalone course in the Fall 2018 semester, intending to demonstrate compelling learning gains and engineering identity development for students who may not be ready for calculus from the first day of classes, but who are ready to be engineers [23–25].

As engineers and educators, we are subject to the definitions of what constitutes an engineer and an educated person, and we are beholden to the *factory model* of engineering education in that we need to *produce* engineers who can fit into society and serve its ultimate needs. Yet as the engineering community and the National Academy of Engineering call for a new type of engineer to serve rapidly changing societal needs [26], we must recognize that our nation's current factory model of engineering education may be unprepared to churn out this new type of engineer, that our systems are still based on the increasingly outdated definitions of what counts as engineering and what constitutes success in engineering education.

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## Appendix

Table 2. Summary of qualitative data collection activity surrounding the GoldShirt Program.

Semester / Activity	Type of Qualitative Data	Duration (approximate)	Number /Type of Participants	How Data Used for Paper
Fall 2014: Pre-Calc Class Sessions	Video of classroom observations	7 class sessions of 50 min each	Students in class + LA + Instructor	Indirectly
Fall 2014: Pre-Calc Instructor Meetings	Video of instructor meetings	5 meetings of ~60 min each	Instructors	Indirectly (see [20] for analysis)
Fall 2014: Grading Sessions	Video of grading sessions	2 grading sessions (1 midterm + 1 final exam), ~5 hours each	Instructors + TAs	Indirectly (see [20] for analysis)
Fall 2013: Focus Groups	Student focus groups	6 focus groups, ~90 min each	Students + researcher facilitators	Indirectly
Spring 2014: Focus Groups	Student focus groups	3 focus groups, ~90 min each	Students + researcher facilitators	Indirectly
Fall 2014: Focus Groups	Faculty focus group	1 focus group; 120 min	Faculty + researcher facilitators	Indirectly
Spring 2015: Focus Groups	Student focus groups	6 focus groups; ~60 min each	Students + researcher facilitator	Indirectly
Fall 2013 and Spring 2014: Instructor and Staff Interviews	1x1 interviews with instructors and GS staff	6 interviews; ranging 30 min to 90 min in duration	GS staff, instructors + interviewers	Directly
Fall 2013, Spring 2014, Fall 2014: Student Interviews	1x1 interviews with GS students	13 interviews; ranging from 40 min to 90 min in duration	Students + interviewers	Directly
Spring 2016	1x1 interviews with students in Pre-Calc	11 interviews; ~60 min each	Students enrolled in Pre-Calc currently or in prior semester (GS and non-GS)	Directly