

HOW BORDERS PRODUCE PERSONS: THE CASE OF CALCULUS IN ENGINEERING SCHOOL

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Mathematics has long been understood to be a “gatekeeper,” which functions to restrict access to educational opportunities due to (a) its central role in formal educational sequences, and (b) the high failure rates often observed in mathematics courses. Failing is an encounter with a type of border: a border that divides a continuous scale into two categories, passing and failing. Typically, this border is understood as restrictive. We present a more nuanced view of the role of borders in mathematics education. In particular, we argue for a view of borders as fundamentally productive objects, and suggest that analytical attention should be focused on who or what gets produced, rather than on who or what gets restricted.

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Mathematics occupies an interesting position in engineering education. On the one hand, the calculus sequence occupies a central role in the curriculum. On the other hand, the calculus sequence is widely recognized by students, faculty, and researchers as a “gatekeeper,” which often functions to push students out of engineering. The gatekeeping role has been ascribed to the calculus sequence due to (a) its centrality in engineering curricula, and (b) the astonishingly high rates at which students fail calculus courses (Seymour & Hewitt, 2000). In this paper, we examine the centrality of mathematics in the engineering curriculum, and we analyze what happens when students fail. This is, by now, well-worn territory. However, our analysis offers new insight into this process.

Failing is an encounter with a type of border: a border that divides a continuous scale into two categories, passing and failing. Typically, this border is understood as restrictive, in that it is used to restrict access to future course work. From this perspective, the work summarized above can be understood as attempts to document the restrictive nature of the border, and to help more students land on the passing side of it. We do not disagree with these efforts. Our goal with this paper, however, is to present a more nuanced view of the role of borders in mathematics education. In particular, we argue for a view of borders as fundamentally *productive* objects, and suggest that analytical attention should be focused on *who or what gets produced*, rather than on who or what gets restricted.

Theoretical framework

We take a critical, situated perspective on learning, in which learning is understood as an ontogenetic process of *becoming* a member of a community of practice. Traditionally, such analyses focus on how both people and communities of practice are produced and re-produced through collective, often asymmetric, participation in cultural practices. In this perspective, *trajectories of membership* are often invoked to describe a person’s “changing participation in changing practices” (Lave, 1996, p. 150), and such trajectories are analyzed to document the ways in which participants are produced as new kinds of people (e.g., Nasir & Cooks, 2009). We adopt a similar focus, but augment it by considering also the role of *objects*— that is, “stuff and things, tools, artifacts and techniques, and ideas, stories, and memories [...] that are treated as consequential by community

members” (Bowker & Star, 1999, p. 298)—in the production of persons and communities of practice.

We draw on two key theoretical constructs to examine the relationship between objects and participation in the production of people and communities of practice. *Trajectories of membership* (Bowker & Star, 1999; Lave & Wenger, 1991) describe the adoption of and conferral of practice-based identities upon newcomers. *Trajectories of naturalization* (Bowker & Star, 1999) describe the ways in which objects—including categories and categorization systems and their attendant borders—enter into and become naturalized within a community of practice.

Such a dual focus is crucial in understanding membership because the naturalization of objects is the process through which norms and values become embodied in practices of everyday life. In this perspective, interactions among people are always mediated by objects, because it is through objects of various kinds that people become seen as a certain type of people:

The relationship of the newcomer to the community largely revolves around the nature of the relationship with the objects and not, counterintuitively, directly with the people. This sort of directness only exists hypothetically—there is always mediation by some sort of object. Acceptance or legitimacy derives from the familiarity of action mediated by member objects (Bowker & Star, 1999, p. 299).

Research method and context

Our research focuses on the experiences of students in a diversity program in the engineering school at State U, a flagship state university in the Western United States. To capture student experiences and the ways in which those experiences were organized within this community of practice, we conducted field-based ethnographic work centered on students, faculty, and staff in the program. We used a variety of fieldwork methods including ethnographic observations of routine activities, ethnographic interviews, and focus groups. Our data include fieldnotes, meeting minutes, and video and audio recordings. Our analysis involved concurrent engagement in data collection and data analysis, using Constant Comparative Analysis (Glaser & Strauss, 1967). We analyzed data from initial fieldwork early in the research process, leading to a preliminary “grounded theory,” which led in turn to further fieldwork to refine the theory, and so on through multiple iterative cycles.

The engineering school at State U is predominantly composed of white, male, middle- and upper-class students. *Access* is a program that seeks to broaden access to the college by admitting a cohort of approximately 30 “next-tier” students to the college each year. Students in the Access cohorts were initially denied admission to the engineering school, but were accepted via the Access program after a second round of admission screening. The Access program has explicit diversity goals, and is composed almost entirely of women, students of color, and first-generation college students. Although these students are admitted directly to the engineering school, they are enrolled in a “performance-enhancing year,” in which they take remedial courses to prepare for courses in the engineering school.

Our initial field work pointed to the centrality of Calculus in the organization of the experience of Access students. Calculus is a naturalized, taken-for-granted object within the community of practice. How did this come to be, and how does calculus organize the trajectories of membership for students? In the sections below, we document the trajectory through which calculus came to be a naturalized part of engineering education, and we describe how one Access student’s trajectory of membership into engineering school became torqued by this trajectory of naturalization.

Trajectory of naturalization: Mathematics as a naturalized object in the engineering curriculum

In the late 19th century, an American engineer beginning his career (in reality, it was almost always “his” career) likely would have started on the shop floor and learned his craft through a practice-based apprenticeship. In those days, engineering was a craft, practiced by masters who relied on “design experience and rules of thumb” (Seely, 1999, p. 289). By 1965, aspiring engineers would experience something very different. Instead of a shop floor, they were likely to find themselves sitting at a desk in a classroom at a four-year university. Gone was the practice-based apprenticeship, replaced by a curriculum based in theory (viz. math and science). Gone too was the image of an engineer as a craftsman, replaced by an image of the engineer as a rational technician. As Seely (1999) traces, over the course of 80 years, mathematics became naturalized in engineering education.

Three broad trends propelled mathematics along its trajectory of naturalization in engineering education. First was the emergence in the U.S. of new technologies such as electricity that appeared to defy the commonsense rules of thumb that had previously guided engineering design. Second, the expansion of land grant colleges, along with an emerging belief in the power of math and science to make the world better, began a general trend to push professional preparation out of apprenticeships and into universities. Even so, university engineering programs at the start of the 20th century were dominated by practical concerns. While these programs involved some math and science, the curriculum remained grounded in practice, and students spent a good deal of time in machine shops and at drafting tables (Reynolds, 1992; Seely, 2005). Finally, an influx of European engineers—who were trained in physics and mathematics, and who approached engineering problems as applied exercises in these disciplines—into the U.S. occurred during the early part of the 20th century.

Concerned by what they perceived as American engineers’ poor technical training, European engineers turned their sights to education. Here the trajectories of European engineers became coordinated with those of U.S. students. Students were entering universities to learn engineering, and European engineers were entering universities to teach it. Guided by a belief that engineering was a technical discipline resting on a foundation of basic mathematics and science, European approaches to engineering began to transform engineering education at the same time as the rise of the rational thinker in the American imagination (Seely, 1999).

The transformation of engineering education was not a smooth one, however, and debates over the nature of engineering and engineering education were “loud and prolonged” (Seely, 2005, p. 116). While this debate took place largely on university campuses, it can be read as a struggle over the nature of engineering itself, as a practice-based trade or as a theory-based profession. Geopolitics entered this debate in the form of the Second World War. Pre-war, engineering faculty were primarily occupied with teaching. Research was rare, and what research was conducted was small-scale, practical research driven by the needs of local industry. During and post-war, the Department of Defense, which was determined to maintain an arsenal of cutting-edge vehicles and weaponry, demanded basic research into explosives, propulsion systems, and materials. Engineering faculty were determined that they, rather than researchers in the basic sciences, should get this funding and its associated prestige. Soon basic research was woven into the fabric of engineering schools, and curricula were twisted to match the demands of the research. Machine shops were replaced with classrooms, drafting tables with desks, and practical experience with math and science. By 1965, mathematics and science were fully naturalized objects of the engineering curriculum (Seely, 1999, 2005).

Today, mathematics is a naturalized, taken for granted part of the infrastructure of the engineering school at State U, encoded into such objects as curriculum flowcharts, shown in Figure 1. One way to see this naturalization is to examine the role of math courses on the one hand, and projects courses on the other. First, notice the centrality of math courses. This can be seen by examining the dependency trees for courses with pre-requisites. All of these dependency trees

include math. Now, compare this with the two “projects courses” that are part of the first and fourth year. As shown, these courses are widely separated and generally disconnected from the rest of the curriculum. Within math and science courses, the course called “Calculus 1 for Engineers” stands out. This is arguably the most important course in the flowchart, as it is part of every dependency tree, and it is the only course for which this is true. Furthermore, it is the first course in each of these dependency trees. In other words, the first step to accessing any course with a pre-requisite is passing Calculus 1.

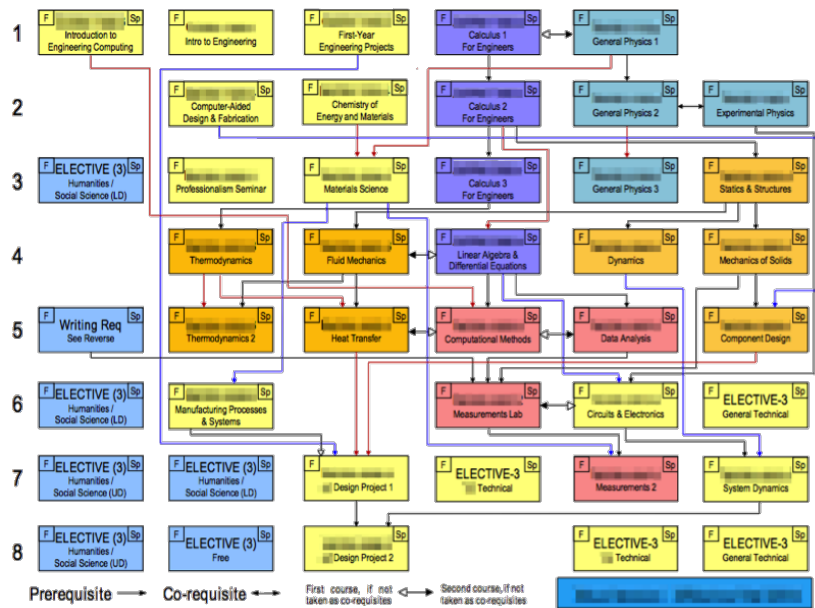


Figure 1. Engineering curriculum flowchart at State U. Course numbers are blurred to preserve anonymity. Numbered rows indicate academic semesters.

Notice the logic inscribed in this object, and the role of borders in producing and maintaining this logic. The rows of the flowchart segment time into semesters. The rectangles segment content into courses, with borders that bound both time and content. The borders between courses can only be breached in a particular sequence, signified on the flowchart with arrows. Taken together the flowchart inscribes a logic of learning as a linear process that occurs within bordered units of content and time.

Moreover, the flowchart necessitates a set of institutional practices for producing and policing borders. Chief among these “*border-policing practices*” are *testing* and *grading*, as these are the practices through which students are classified into courses, that move students from course to course. In overview: tests are composed of problems; students provide solutions to these problems by making inscriptions—a process through which students translate some piece of themselves into marks on paper; and these inscriptions are mobilized into a separate room where instructors translate them into scores—a different set of marks on paper. These scores are then aggregated and translated into a grade, yet another mark on paper. Final grades, then, are produced via a cascade of inscriptions. Students produce inscriptions in response to test problems, these inscriptions are assembled and translated into a numerical score, and these numerical scores are assembled and translated into a final grade.

These grades serve as the mechanism by which the institution polices the borders inscribed in the flowchart. Depending on the grade a student receives, she is either granted or denied passage through the flowchart. Passage from one course to the next is binary—the border either opens or it doesn’t—

and this gives certain categories heightened importance. For Access students, the category that determines passage into the next math class is a B-.

In addition to doing institutional work, the flow chart also serves as a resources for students to locate and construct themselves in relation to the institution (Nespor, 2007). The flowchart translates time (measured in semesters) to space, and produces a standardized “path” onto which students reckon themselves in spatial terms. For example, students talk about being “ahead” or “behind.” These reckonings are value-laden; it is much better to be “ahead” than “behind,” and being “behind” brings with it costs in terms of money, time, and status. Thus the borders of the flowchart don’t just serve to segment content and time, they also serve to produce students’ institutional identities. As such, the borders do both institutional and identity work, as we highlight in the case below.

Trajectory of membership: Mary

Mary is a white female student whose experience in the Access program has been shaped by mathematics and its associated boundary-policing practices. She came into the program having taken calculus in high school, and expected that she would take calculus during her first semester. She never had the option. In order to understand why, we have to examine the history of the Access program, and its relationship to calculus.

The Access program has enrolled six cohorts of students. From the beginning, the program has faced opposition from some faculty in the school of engineering, who see the program as a sign that the school is “lowering standards.” This opposition became especially salient for Professor Turner, the director of the Access program, in the program’s third year when it became clear that students in the Access program were not passing Calculus at a rate commiserate with the rest of the school of engineering. In a focus group she explained, “when we saw our kids failing [Calculus], were like, ‘oh crap, we’re about to lose this program.’” Professor Turner recognized that at State U, calculus doesn’t just legitimize students, it legitimizes *programs*.

Calculus I for Engineers at State U has a 30% failure rate, and, because it’s so central in the flowchart, this leads to attrition in the engineering school. Still, it’s largely untouchable. From Professor Turner’s perspective, “changing calculus is like moving an elephant—a mountain.” So rather than change calculus, the Access program changed their remedial sequence. They worked with the math department to create a new Pre-calculus course with the explicit goal of making Access students “calculus ready.” Because passing calculus is so important for engineering students (and the programs they populate), Professor Turner decided to enroll all of the students in Mary’s Access cohort in Pre-calculus, regardless of each student’s history with mathematics.

While Professor Turner made the decision to enroll Mary and the rest of her cohort in Pre-calculus in order to enhance the legitimacy of Access students and the Access program, the decision initially had the opposite effect for Mary. This is because the nuance of such a decision cannot be captured on the flowchart, which enforces a standardized pathway through the curriculum. Professor Turner’s decision pushed students like Mary outside of the borders of this pathway, into into the margins of the flowchart. Mary explained:

Almost all of the classes here for engineering are based off of calc, so if you’re not caught up in calc you’re gonna be behind in all of your other classes as well. And there’s like no getting around it. So that means I’m definitely way behind other people in the engineering school.

One the one hand, such a position is expected for Access students. It’s a natural outcome of the “performance enhancing year” that is at the heart of the program, and of Professor Turner’s decision to enroll all Access students in Pre-calculus. From this perspective, Mary, who took Calculus I in the fall semester of her second year at State U, isn’t behind at all. She’s exactly where the Access Program expects her to be. However, such a perspective fails to account for the lived experience of

students like Mary, who took what she calls “freshman classes” during her sophomore year. During an interview, her voice cracked as she described what this is like:

[It’s] kind of embarrassing almost, cause you feel like you can be smarter than this, and like moving on, but you’re not. Yeah. I don’t know. I, it’s just, I don’t know... I don’t know (softly). I can’t- I don’t know how else to describe it.

The margin of the flowchart is not a neutral space. In the margin, Mary questioned her legitimacy as an engineering student.

This is not the only way that mathematics and its associated border-policing practices affected Mary’s sense of self. She describes herself as someone who tries to “think things through,” and “show all the steps.” For her, this is how to make learning “stick.” However, at State U, Mary experienced mathematics as an exercise in answer-getting under time pressure. In the segment below, she talks about doing slow, careful work in mathematics.

Well, it’s not good if you want to actually get stuff done. [Last semester] I would just run out of time to do stuff, because I spent so much time like, going through... And it’s not a good thing for exams because that’s kind of like, you’ve got to know it, you’ve got to write it out really fast. And you’ve got to know all the stuff, you can’t just like stop to think for too long, otherwise you run out of time.

As Mary describes, borders are important in testing. Tests are temporally and spatially bounded. Inscriptions that are produced outside of these borders are not allowed in. Hence, “you’ve got to write it out really fast,” because inscriptions made outside the temporal border aren’t mobilized into the grading room. If you “run out of time,” you bump up against the impermeable temporal border of the test.

Mary “ran out of time” on her tests in Pre-calculus, and this turned out to be consequential. At the end of her first semester, her grade was below the binary cut-off and she therefore had to repeat the course the following semester. For Mary, mathematics was refusing to be naturalized, and this pushed her further into the margins of the flowchart. In large part, this was due to the way that mathematics was construed at in the engineering school at State U. Because the border-policing practices privileged answer-getting and speed over reasoning and thoughtfulness, her pensive style went unrecognized by the institution.

Mary “passed” Pre-calculus after her second semester. Looking back, she describes Pre-calculus as “very important” for calculus. In large part, this is because exam problems *made* it important:

[Pre-calculus] was very important. The first test was like over all things pre-calc basically. With a couple of calc things. [...] They had a question on absolute value. And you learned like a lot about absolute value and translations and stuff [in pre-calc]. And you needed that information to solve a certain problem on the calc exam.

Under these circumstances, Pre-calculus helped Mary to perform on the consequential knowledge displays (Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008) that police the borders of the flowchart. As such, it helped propel Mary out of the margins of the flowchart and onto the standard pathway.

But it is in the margins, after Mary failed her first semester of Pre-calculus, that something even more extraordinary happened. Because of her non-standard position as a student repeating Pre-calculus, Mary was in a small class of students. In this environment, her instructor came to know Mary and her thoughtful style. This led the instructor to ask Mary to be a Learning Assistant (LA) for the Pre-calculus course in the following year. LAs are undergraduates who help to facilitate small-group interaction in large-enrollment courses. As an LA, Mary was positioned as an expert in mathematics. Students looked to her for help, this helped to affirm Mary’s legitimacy:

You feel like, kinda, proud of yourself and like, um, really happy that you got to help someone and like, make their life a little easier. Um, it's just, yeah, a really good feeling.

In addition to helping students, she worked with and socialized with Pre-calculus instructors, she helped to grade exams, and she conducted an independent education research project that she presented at a poster session on campus.

In some ways, mathematics—and the boundary-policing practices that allow it to be institutionalized—pushed Mary into the margins of the engineering curriculum, causing Mary to question her identity as a member of the engineering community. This began with the Access program's decision to enroll Mary in Pre-calculus—a decision that ensured that Mary would always be behind on the flowchart, but which, in retrospect, helped Mary gain legitimacy in calculus. It continues with the ongoing violence that timed tests inflict on Mary's sense of self. At the same time, the margin became a space of possibility for Mary (hooks, 1989). In the margin of the flowchart, mathematics pulled Mary into a position of some power and authority within the engineering school, allowing her to build relationships and participate in practices that affirm her legitimacy in the community.

Conclusion: The role of borders in the production of persons

Foucault (1978) presented a radical new vision of power. While the received view was (and continues to be) that power was coercive, Foucault argued that, on the contrary, power was fundamentally *productive*. This was not an argument that power was benign, just that power produced people and society in particular ways.

In this paper, we advanced a similar argument for the role of borders in mathematics education. We first documented how, in its trajectory of naturalization within engineering education, mathematics became intertwined with institutional borders. Next we illustrated how these borders (and their associated border-policing practices), are fundamentally productive objects that constantly work to produce students in particular and complex ways. To be sure, borders do violence to Mary. They create margins and produce suffering, as Mary questioned her legitimacy as an engineering student. But at the same time, the very same margin became a place of possibility for Mary, and helped to produce her as a privileged member of the community. There is little doubt that Mary has been produced in complex ways by the borders associated with mathematics.

Mary's story is just one of the many we could have told about the complex ways that borders become productive in mathematics education. For many of the students that we have worked with, borders have produced both injury and possibility. For example, another student in the Access program, driven by fears that his marginality (due to mathematics) will lead to him getting “kicked out of the engineering school,” designed and patented a “high-end upgrade for 3-D printers,” which he is currently selling online. Another collection of Access students formed a student-led group to argue for more individuation in the Access program, largely in response to Professor Turner's decision to enroll entire cohorts in Pre-calculus.

We stress that when we argue that borders are productive, we are not arguing that borders are benign. Borders produce students in complex ways that cannot be encapsulated *a priori* using simplistic categorizations like “good” or “bad.” Instead, our argument is, to paraphrase Jean Lave (1993, p. 8): *that borders are productive is not problematic. What gets produced is always complexly problematic.* We argue, then, that more analytical attention should be focused on what gets produced by the borders in mathematics education.

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