Introducing Actor-Network Theory Via the Engineering Sophomore Year

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Abstract

The second year or sophomore year of most 4-year engineering undergraduate programs includes completion of the final fundamental math and science courses required for an engineering degree. We believe the intensive examination of this critical year in undergraduate engineering education is warranted, and advocate for a new perspective in analyzing the social and cultural environments of gateway engineering mathematics courses of the sophomore year - specifically Calculus 3 for Engineers and Differential Equations & Linear Algebra. Our study seeks to identify how students connect to various resources, peers, and content and to what effect as they navigate the curriculum of these high-stakes prerequisites for subsequent major-specific coursework. We study ethnographically the experiences of undergraduate students, graduate student teaching assistants, and faculty instructional staff as they traverse these courses, in order to map out the social and cultural terrain upon which learning, status, and grades are negotiated. Inspired by a novel theory from Science and Technology Studies (STS), we take an actor-network view of sophomore engineering, tracing connections between human actors and non-human elements including mathematical concepts, places, objects, and resources to demonstrate how students are translated to varying degrees through sophomore mathematics courses into actor-networks of engineering. Actor-Network Theory encourages a fresh perspective of sophomore engineering that affords researchers a systems-level view of these critical gateway courses and suggests fundamental questions regarding the nature of our courses and how they got this way in the first place. This paper introduces Actor-Network Theory and the four moments of translation, describes the methods for our research study of sophomore engineers as informed by Actor-Network Theory, and provides justification for the use of this novel social theory in engineering education research.

Introduction and Research Purpose

The sophomore, or second year, is a critical period of development for an engineering student. The sophomore year curriculum consists of the final math and science requirements for all engineering disciplines. Students who have difficulty with or fail a fundamental class during their first two years can seriously delay their graduation date or be discouraged from finishing the degree. Such experiences are known to dissuade students and have been correlated with early departure from engineering majors. Data from our local site indicate that 82% of engineering students return for the second year, while only about 69% continue into the third year, while there is a much smaller attrition rate between the third and fourth years (see Figure 1). National data on engineering student retention is typically reported for students persisting until the eighth semester, and has been shown to range from 38% to 52% across a range of institutions. Consequently, direct comparisons between the local site and national averages are not possible.
Typically, engineering educators have focused on curricular interventions to improve the first-year experience and have researched the development of student cognitive characteristics such as attitudes and skills. However, little attention has been given to understanding the environmental or structural barriers that engineering students face during the second year of their education, a year which represents considerable retention risk in engineering. The courses of the sophomore year mark the descent into “the valley of despair” as students are confronted with a seemingly endless march of technical requirements chained together with little wiggle room for electives or failure. The second year features gateway courses that eventually lead to the practice of engineering and courses that initiate students into greater levels of abstraction and analytical engineering problem solving. Consequently, we have chosen gateway courses endemic to the sophomore year as our main study sites.

Typical undergraduate engineering curricula require at least four mathematics classes: Calculus 1, Calculus 2, Calculus 3, and Differential Equations & Linear Algebra. At the large public university we studied, the Calculus courses must be taken in sequential order with Calculus 3 (Calc 3) and Differential Equations & Linear Algebra (Diff Eq) typically taken during the second year. We focus on Calc 3 and Diff Eq because the sequencing of these courses matches our desire to focus on the sophomore year, and because these two courses are the predominant prerequisites for subsequent major-specific technical courses across the engineering college.

For example, in most Mechanical Engineering curricula, Calc 3 is a prerequisite for one required course (Thermodynamics), while Diff Eq is a prerequisite for four required courses. In turn, these required courses then serve as prerequisites for the next level of technical coursework, eventually leading towards degree completion (see Figure 2). Consequently, difficulty or failure in either Calc 3 or Diff Eq can severely impact a student’s ability to progress into subsequent courses within their major, causing a compounding effect for students navigating the inflexible curriculum, opening the door to thoughts of attrition. In other words, the engineering curriculum is a rigid network that can only be traversed along officially acceptable prerequisite pathways.
Calc 3 and Diff Eq are also known for being difficult, both in workload and in content, as they mark the transition into more ambiguous and nuanced material. As one instructor of Calc 3 at the large public university under study explained to students on the first day of classes:

[This class is] somewhere between Calc 1, where everything is perfectly defined, and the 4-year end where nothing is defined and you don’t know all the answers… it [uncertainty] has to start somewhere and that is here.

This transitional environment is ripe for high-impact educational research and analysis, particularly given the large number of students in each of the courses and the importance of these courses along every engineering student’s educational trajectory. Furthermore, statistics taken from our local site over the last twenty years indicate that 15-25% of the students enrolled fail Calc 3 each semester, with similar but more varied failure rates for Diff Eq. The students who do not pass these two courses represent a significant fraction of the sophomore cohort that has to retake the classes at substantial financial and opportunity cost, or choose to leave engineering for an alternate major. The high failure rates of these courses, representing a quarter of the cohort, correspond with severe consequences for the students who do not receive passing grades, as repeating a single mathematics course causes cascading effects through the rigid chain of curricular requirements for an engineering bachelor’s degree.

While the first year has been rigorously studied in the engineering education literature, understanding the second year and the climates of gateway courses such as Calc 3 and Diff Eq is critical for understanding the experiences of our undergraduates and how we can best inspire them to remain in engineering⁸.¹⁰ Recent scholarship in the field of engineering education has also indicated the importance of student experiences in mathematics courses to subsequent completion or transfer out of engineering degrees¹⁰. This study looks intensively at the social and cultural environments of these courses, investigating how students organize around resources including textbooks, professors, peers, solutions manuals, teaching assistants, and more. While prior research has mentioned and illustrated the impact of math courses on student progress through 4-year undergraduate degree programs, we focus specifically on the lived experiences of engineering students during their sophomore year. What happens when we begin to look into the previously black-boxed, unquestioned traditions of engineering mathematics courses? The ultimate aim of the study is to understand the organizing conditions for student success or lack of
success in passing these decisive courses, to better explain how a student can climb over or fall down from the metaphorical cliff of engineering mathematics.

**Background**

*Call to Action: A Need to Study Engineering Sophomore Year*

The sophomore year is a critical juncture for engineering students and it is important to understand it better. While large-scale longitudinal studies and smaller-n case studies highlighting student trajectories through all four years of engineering undergraduate have touched on the experiences of sophomores, very few publications focus exclusively on this critical second year. The studies that do focus on the second year mostly investigate and detail curricular interventions employed in sophomore-level courses, reporting students’ performance/grades and instructor opinions of the courses post-intervention\(^{11-13}\). Several articles discuss the process of integrating design as a learning objective into sophomore level courses, with details regarding curriculum, assessment, faculty experiences, and student course ratings\(^{12,14,15}\). A few studies investigate novel means of peer learning in which sophomore students interact with seniors or compare their knowledge with graduate students, generally focused on conceptual knowledge gains and student feelings of confidence in problem solving skills\(^{16,17}\).

With the publication of the 2014 *Cambridge Handbook of Engineering Education Research* (CHEER), the field has acknowledged the relative lack of studies focused on sophomore year and junior year\(^{18}\). One chapter from the handbook focuses on these middle years (sophomore and junior, or second and third), again recognizing that the majority of the curricular design of the middle year courses has remained unchanged for decades\(^{7}\). The chapter demonstrates a need for meaningful transformation of the courses that typify the middle years, and the authors declare the need for a research and reform agenda for these middle years of engineering education that includes:

- Research focused specifically on the sophomore year and junior year in engineering. This could build on and contribute to the multidisciplinary discourse on the ‘sophomore slump’.
- Engineering educators should be more purposeful and thoughtful in designing educational experiences for the second and third year by integrating content, outcomes, assessment, and pedagogy. Think of it as design. Bring in engineering expertise.
- Make the learner and community an integral part of teaching process beyond the first year. Address diversity as part of the equation, not as an afterthought. Learn from decades of research on gender and race\(^{7}\).

This three-part call to action for the middle years curriculum is meaningful though not highly targeted. The first part explicitly addresses the need for research on the sophomore and junior years, while the second and third parts are practitioner-based, suggesting actions for engineering educators and administrators. While certainly warranted, this call to action is not easily actionable. Well-intentioned engineering educators and administrators of the middle years who wish to enact change have little foundational research to guide them in implementing new policies or new educational experiences.
The National Science Foundation (NSF) has further propagated this call to action on researching the sophomore year. The new “Revolutionizing Engineering Departments” or RED program solicitation included deadlines in late 2014 for proposals specifically addressing the ‘sophomore slump’ of the middle years of engineering education\(^9,19\). Policymakers and researchers alike thus see the contemporary need to intensively study the sophomore year of engineering, and are taking steps to address the current lack of information on this understudied period in an undergraduate engineer’s trajectory.

Our study seeks to address these calls for action and research agendas by focusing on the sophomore year in engineering undergraduate, which remains a critical transition time for students pursuing engineering degrees. Instead of encouraging the continued development and assessment of novel interventions designed to impact the sophomore year, our study inquires into the current state of sophomore engineering, so that we can be informed when making and advocating for changes, or trying to ‘revolutionize engineering departments’ in line with funding opportunities. We wish to examine the social complexity of the everyday lives of sophomore engineers, to unearth the elements that are not accounted for when looking at the impact of a single intervention on a designated class or program. Moving away from cognitive studies that isolate individual factors, we attempt a sociocultural examination of the lived experiences of sophomore engineering students within complex learning environments.

**Theoretical Framework: Actor-Network Theory**

*Actor-Network Theory*, or ANT, is a theoretical perspective that originates from the field of Science and Technology Studies (STS). As used in this study, ANT is a standpoint, a set of concepts, a way of looking at social and cultural situations that encourages examination of how *heterogeneous actors* including people, things, courses, cognitive constructs, and more become connected to one another to form an *actor-network*, the conditions under which these varied connections develop, and how different strong and weak connections are expressed. ANT was one of the first social theories to consider humans and non-humans as potential *actors*, together instead of separately, to create a new type of sociology that is not restricted to just things or just people. In the language of ANT, this is known as *symmetry* or *metrical analysis*, as Latour and other ANT scholars suggested that researchers should not impose “any distinction between ‘things’ and ‘people’ in advance”\(^20\).

In addition, ANT uniquely encourages researchers and theorists to take the place of non-human artifacts, to see the world from a different perspective. Putting oneself in the shoes of a novel technology, for instance, enables a viewpoint on how that technology came to be that is differently informative than the typical story from the perspective of the human inventor\(^21\). Recently, the engineering education research community is also beginning to acknowledge the importance of non-humans in terms of material and representational artifacts, as learning engineering is dependent on tools including software programs and large equipment, and representations including equations, flowcharts, diagrams, etc.\(^22-24\)

ANT comes with its own vocabulary, as words like *actor*, *actor-network*, *symmetry*, and *translation* take on nuanced meanings in the language of ANT. Here we introduce and define the ANT concepts of *translation* and its *four moments* for further understanding:
• *Translation* is classically known as the central work-process of ANT\(^2\) and denotes the process wherein “an entity, human or nonhuman, becomes selected, enticed, persuaded and partially or fully changed in ways that mobilize it to join the *actor-network’s* movements”\(^3\). *Translation* is evident when “one element stands in for another or many others, just like a word in one language stands in for another, or a symbol stands for many strings of symbols”\(^4\). *Translation* occurs within four overlapping stages or moments of translation, which are *problematization, interessement, enrollment, and mobilization*\(^5, 6\).

• *Problematization* refers to the ways network-builders define allowable identities for other *actors*, frequently situating themselves at *obligatory passage points* within the *actor-networks* of relationships being built.

• *Interessement* “describes the efforts of *actors* to encourage others to adopt their views and is a form of buying into a point of view,”\(^7\) or a moving into place of alliances between *actors*.

• *Enrollment*, signifies a confirmation of successful *interessement*, as alliances become locked in and certain instead of uncertain.

• *Mobilization*, the last moment, explains how an *actor-network* becomes ordered and persistent through space, describing how some *actors* can act at a distance while others become mobile and transportable from place to place.

Additional illustration of these concepts and how they apply to our study is provided in the Actor-Network Theory in Action section, following the Methods.

A slogan of ANT is to “follow the actors themselves” as they establish varied and dynamic connections in the social terrain under investigation\(^8\). For our study, we examine human and non-human actors *symmetrically*, seeing how objects like curricula and textbooks can be connected as meaningfully to other elements in an *actor-network* as a student to an instructor. Following the heterogeneous actors means tracing the associations made between all actors and artifacts in a given system, adding new elements as new connections are made and letting go of elements whose connections fade. By starting with the students, teaching assistants, instructors, and artifacts involved in sophomore-level required mathematics courses, we have a foundational set of *elements* from which to expand the *actor-network* and analyze which conditions are conducive to *actor-network* formation vs. dissolution. We record observations of course events both official and informal; conduct semi-structured interviews with human actors that can speak for themselves, and gather artifacts and documentation that assist in tracing the connections made by non-human objects. This method is intended to trace out connections and map student *actor-networks* in the university setting.

*The Present Study*

The understudied sophomore year is a pivotal time for engineering undergraduates as passing or failing grades determine which disciplinary *actor-networks*, or majors, students come to call their own\(^9\)\(^10\). In the language of Actor-Network Theory (ANT), we wish to ask how students become *enrolled in the actor-networks* of engineering sophomore year and to what consequence. We demonstrate how *Actor-Network Theory* can guide interpretation of various data: participant observations from Calc 3 and Diff Eq course events; interviews and focus group discussions with students, teaching assistants (TAs), and instructors; curricular artifacts from current and
historical implementations of these courses; and informal data collected from following student and curricular actors through everyday activity. The ultimate goal of this type of study is to identify actor-network connections and gaps between sophomore engineering cultures, students, and teachers, and how this actor-network travels through the space and time of an undergraduate engineering program.

To accomplish this goal, our study investigates the following primary research question:

RQ1. How are students enrolled in the actor-networks of engineering during their sophomore year and to what consequence?

Methods

We choose a qualitative approach as fitting for an exploratory study into the under-researched culture and social organization of gateway courses in the engineering sophomore year. We employ ethnography in this study because it allows for close investigation of engineering culture as enacted in public spaces of lecture halls and study rooms and as experienced by engineering students privately. Our ethnographic approach to studying sophomore engineering encourages the research team to gather data in multiple forms: classroom observations, informal conversations with students around campus, semi-structured interviews with students, graduate teaching assistants, and teachers, and artifacts related to our focal courses of Calc 3 and Diff Eq.

As is customary in qualitative research, data collection and analysis occur in overlapping iterations, as emergent themes from early analysis enabled the research team to adjust the parameters of data collection to better suit the evolving study’s focus. The data collection and analysis process is presented here in a linear fashion for readability, but in reality the process is simultaneous and iterative.

Data Sources and Collection

Data collection for this study began ethnographically at the fall start to an academic year with the targeted observation of two lecture sections of Calculus 3 for Engineers (Calc 3) consistently throughout the duration of the semester. Fieldnotes documenting classroom events, interactions, and student behaviors were taken electronically in real-time by a member of the research team to establish a baseline primary record of each class meeting. Particular attention was paid to the public discourse heard in the classroom, as questions and statements made by students were recorded verbatim in the fieldnotes. Key phrases from instructors regarding student attitudes and recommendations for studying or conceptualizing the course material were also recorded verbatim in the fieldnotes to the best of the observer’s ability during each class. For the larger lecture sections, the researcher moved around the lecture hall during the semester to vary the context of the observations, noting the habits of the students around each different seating location and striking up informal conversations before the lecture periods with the students proximal. For the smaller lecture sections and recitations of less than 30 students, the researcher stayed in the middle or back of the room to afford a view of student activity around the room.
Course activities including recitations, review sessions before each midterm, and a midterm exam were also observed by a member of the research team with accompanying fieldnote record. Artifacts, including course syllabi, homework assignments and solutions, exams and exam solutions, projects, worksheets, textbooks, etc. were collected for later analysis. In totality, over 95 hours of course activities were observed during the fall 2013 semester. At the end of the fall semester, semi-structured interviews were conducted with eight students enrolled in the course and one course instructor. The eight students were chosen strategically to represent both lecture sections under observation and a spectrum of seating locations and perceived attentiveness during lectures, as students who took notes diligently and students who browsed Facebook and other online networks were interviewed. These interviews were approximately 60 minutes long, audio-recorded, and later transcribed to text with personal identifiers removed for further analysis.

In the following spring semester, data collection continued with targeted ethnographic observation of three lecture sections of Differential Equations & Linear Algebra (Diff Eq). Each of the lecture sections was attended once a week by a researcher during the 16-week semester. Similar to the prior semester, observational fieldnotes were taken in each class meeting a researcher was present for, with 48 total hours of observations completed. Artifacts specific to this course were collected as well. We performed follow-up interviews with the six students still enrolled in engineering at the end of the spring semester, adding one additional student interview subject to supplement student perspectives on these gateway mathematics courses. Interviews were conducted with only one of the three instructors under observation as the other two instructors declined to participate following the conclusion of the semester. All interviews are semi-structured, audio-recorded, and cleaned of personal identifiers in the resulting transcripts.

Four graduate Teaching Assistants (TAs) from the gateway mathematics courses under study were interviewed during the third semester of the study, and follow-up interviews were conducted with the two instructors who were willing to participate in the research. Questions for these follow-up instructor interviews and TA interviews arose from in-process analysis of the data, centered on major themes from prior interviews and observations. Focus groups with engineering students were convened, with a total of eight student participants discussing contentious issues related to their experiences in the gateway math courses. Contentious issues included what students thought of the midterm and final exams in these courses, what students believed to constitute cheating on homework, how students used diverse resources to assist in completion of homework and course assignments, what unofficial activities students did during lecture periods, and general student opinions of and reflections on their mathematics experiences.

Additional data collection in the third semester included gathering historical artifacts related to the engineering mathematics curriculum and specifically Calc 3 and Diff Eq. Trips to multiple library archives to collect historical course catalogs, building maps and floor plans, architectural drawings, and administrative documentation all helped to shed light on the origin of the current curriculum as implemented and observed in the prior two semesters. See Table 1 for summary of this study’s data collection.
Table 1: Data Collection Activities Over Three Semesters

<table>
<thead>
<tr>
<th>Semester</th>
<th>Focus</th>
<th>Data Collection Activities</th>
<th>Hours of Researcher Observation</th>
<th>Artifacts Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester 1 (fall)</td>
<td>Calculus 3</td>
<td>Intensive observation of 2 lecture sections (1 instructor); 1 recitation section; 8 student interviews; 1 instructor interview</td>
<td>95</td>
<td>Syllabus, homework assignments, exams, projects, textbook</td>
</tr>
<tr>
<td>Semester 2 (spring)</td>
<td>Differential Equations &amp; Linear Algebra</td>
<td>Weekly observation of 3 lecture sections (3 instructors); 7 student interviews; 1 instructor interview</td>
<td>48</td>
<td>Syllabus, homework assignments, exams, projects, textbook</td>
</tr>
<tr>
<td>Semester 3 (fall)</td>
<td>Follow-Ups</td>
<td>3 focus groups with students; 4 interviews with graduate TAs; 2 follow-up instructor interviews</td>
<td>N/A</td>
<td>Grade distributions from past years, FCQ scores, TA coordination policies, historical documents</td>
</tr>
</tbody>
</table>

Participants

For our study, we chose two mathematics courses that are generally taken in the second year of engineering school, though first-year, third-year, transfer, and non-traditional students are enrolled as well. These diverse student demographics add to the interesting cultural landscape of these courses, as a precocious freshman unafraid to dominate a sophomore-level course can affect how other students in the course perceive it and themselves. Generally, the majority of students in the courses we observed are considered sophomores, but not all. In the first two semesters of the study, we observed one small “honors” lecture section of less than 30 students and the rest were large lecture sections of over 100 students. Students in the honors sections had the same recitations, homework, exams, and projects as the rest of the sections, with a smaller classroom instead of a large lecture hall. Interview subjects were chosen from both honors and larger lecture sections, from a variety of majors.

The instructors of the courses under study were all experienced in that they had each taught the courses at least once before, and in some cases many times before. The research team informed the instructors under observation early on during the semester with a short description of the study and its purpose. Instructors generally ignored the presence of the research team in the classes, enabling surreptitious participant observation in the classroom. Graduate student teaching assistants (TAs) were chosen for interviews based on convenience and experience. All of the TAs interviewed were at least in their second year of graduate school, and were serving as TAs for at least their third full semester in engineering mathematics.
Qualitative Data Analysis

Analysis and collection of data occurred in overlapping cycles, with all data collected by the end of the third semester of the study. Interviews and focus groups were transcribed into text and then input into the qualitative analysis software package NVivo, along with the fieldnote observations and salient artifacts from the courses under study. Analytic memos were written and discussed by the research team during the data collection period and afterward, based on emergent topics from the data. Additional artifacts were procured from research participants based on interview and focus group transcripts, to further illustrate aspects of participant stories and experiences in these sophomore level mathematics courses. Historical artifacts were compared with contemporary versions, where appropriate, and informed analytic memos regarding the curricular structure of the mathematics courses through time.

Multiple iterations of coding schemes were developed based on the research paradigm at the time. A descriptive codebook was created initially to categorize the data by major course events and actors including professors, exams, projects, homework, lecture, recitation, and more. Later an actor-network codebook was constructed in-line with the conceptual framework in order to categorize the different relationships and actor-network connections made between the various actors under study, including person-to-person connections like students relating to their peers, person-to-material spatial connections like TAs connecting to their classrooms and office hour spaces, and person-to-representational/inscriptive connections like instructors connecting to the mathematical concepts and content of their courses. Attention was also paid to the strength of the various actor-network connections, as loosely connected items were contrasted with strongly connected relationships among all types of actors.

Findings of the study are initially descriptive, as our intention is to first map out the current state of sophomore engineering to be informed before trying out educational interventions. Actor-Network Theory provides the basis for interpreting our data, as we identify salient actors and their interactions, as well as their movements and translations into actor-networks.

Actor-Network Theory in Action: Sophomore Engineering Mathematics

In more traditional engineering education studies, this section would be presented as findings or results. In this paper, we have framed this instead as ANT in action, as we are illustrating ANT concepts “in action” in engineering undergraduate. We find that the four moments of translation are relevant in the context of sophomore mathematics in several ways. Looking at each stage, or moment, highlights the relevant actors present at each negotiation of identity and actor-network formation. While students, faculty, and graduate student TAs are obvious human actors, we see that the curriculum, tests/exams, classrooms, office hours, grading/grades, software, projects, concepts, labs, transcripts, etc. are each prominent non-human actors as well. The interactions between the human and non-human actors are worthy of study, and necessary for understanding the full scope of actor-network activity in engineering sophomore year. We see how the students, course materials, curriculum, etc. are collectively translated by the administration, instructional staff, and overall educational system, and the consequences of this translation process for an engineering education.
The required engineering mathematics courses of Calc 3 and Diff Eq serve as obligatory passage points that engineering students must progress through in order to continue with their engineering coursework. The prerequisite dependencies exhibited in curricular flowcharts make this positioning unmistakably clear: students must pass these courses or else they will not be engineers; their identities as engineers are defined and restricted by their ability to do math. This is problematization, or the defining of positions and identities within an actor-network, in engineering sophomore year. The administration and institutional system further delineate allowable identities; “instructors” and “teaching assistants” have roles defined by their course assignments, pay grades, and job titles each semester.

Interessement in sophomore engineering is evident through the time-intensive workload of Calc 3 and Diff Eq, and engineering in general. The ‘greedy curriculum’ of these mathematics courses effectively cuts engineering students off from alternate pursuits or interests, as there is little time to spare for extracurricular clubs, sports, or socializing with non-engineers. As these courses are also mandatory obligatory passage points (OPP), engineering students must be interested (interessed) in passing these courses if they wish to progress through the curriculum towards eventual graduation with an engineering degree. Students are bought in, heavily invested in the curriculum and the institutional perspective that these mathematics courses are necessary.

Enrollment, or the confirmation of interessement, occurs at multiple levels – students who are interested (interested) in progressing past Calc 3 and Diff Eq must do their homework, complete projects, and most importantly, study for and pass exams (a highly influential non-human actor). Students’ interessement is confirmed through the official processes of grading, receiving passing scores on midterms and final exams, and thus becoming enrolled into subsequent semesters and junior year. Each assignment/test is an opportunity for negotiation between student and instructors, interessement and enrollment. In engineering sophomore year, enrollment takes the form of passing grades on transcripts, institutional recognition that a student has appropriately stuck to their undergraduate engineering coursework and can proceed to the next phase of their education. Yet, there is a great deal of complexity in the enrollment process that still needs to be uncovered, and the consequences better understood.

In consideration of sophomore mathematics prerequisites, mobilization, or how an actor-network becomes ordered and endures through space, occurs in several ways. The process of condensing a semester of work, learning, and student experience into a single letter grade is one example of a chain of mobilizations that results in one highly mobile representation, the final course grade, which encapsulates many subsidiary events and assignments and itself serves as an OPP. Occasionally these representations are inaccurate or misleading, in the cases of students passing classes without really learning the material, or vice versa - students failing the classes due to test anxiety or other causes while possessing adequate command of the material. Mobilization in this context can also refer to the vast amounts of resources that are enlisted in the efforts of teaching and learning Calc 3 and Diff Eq: the many graduate teaching assistants (TAs) that are required to administer recitations, office hours, and teach the lab courses which enable students to learn the required software for completing course projects; the hours and hours of grading performed by the instructional staff in order to assign representative grades to each assignment, test, and overall; and the number of lecture halls, classrooms, help rooms, online resources, and more that
provide space for instructors to teach and students to learn as they circulate through these spaces, both virtual and physical, throughout a given semester.

Overall, students are translated through these courses from sophomores into juniors, from being on track to graduation or behind their peers. Students who resist making meaningful connections to the content material in these required mathematics courses might be prohibited from reaching subsequent coursework, altering the shape of their student actor-networks and the institutional actor-network that surrounds them. A failing grade can also be interpreted as a failure to enroll the student in the actor-network of engineering, as the student was not sufficiently interested to learn the material or perform on the stage of the exams. As the mobile representation of the course grade is based predominately on exam grades, we see the non-human element of exams as critical in organizing actor-network activity, as important actors which have lasting effects on the humans involved.

An extended interview excerpt with an experienced instructor of Calc 3 further highlights the processes of translation that the curriculum and instructional system have undergone in the last twenty-some years:

Instructor: Our system has changed over the years. In the old days it was a whole lot simpler. In some ways, less is more. You know it's like the good fairy goes around, “Hey wouldn't it be great if we do this, and this, and this?” and it's like, yeah, they're all great ideas, but when you implement them all you're just overworking the students. They have to hit this target and this target and this target, and for example, in Calc 3 and I actually agree with the students on this, I mean, there's too much work in it. And, I can't undo that, but over the years, you add things to the list but you never take anything off. And, that's something that's changed on our part, that's not students have changed, and I don't think that's helpful to the students. You know, just adding to the burden, you know at some point they're just too busy doing and not learning, so.

Interviewer: You're thinking of things like projects, for instance? The online homework?

Instructor: Yeah we've got 3 projects, we've got a lab class, we've got online homework, we've got homework from the textbook, we've got the additional problems, and they have to go lecture, and they have to go to recitation, and they have quizzes, and the list gets so long. Even as the coordinator of the course I'm not in a position to say, “we're going to cut this and this and this.” There's this whole machine within the department that anything has to be cleared with to make structural change. And so, right now, given the number of students coming in and the amount of work, I think it's a bad combination.

The instructor is describing translation in hindsight, with the primary results of the translation processes surrounding the Calc 3 course being the “overworking” of students, “adding to the burden”, causing students to be “too busy doing and not learning”. As the instructor describes, “the good fairy” was a person at some point who defined the identities of the faculty and administrators as powerful people who wanted better education for their students, while situating
their “great ideas” as the obligatory passage points to get there. In bringing forth the ideas for curricular additions like projects, lab courses, online homework, recitation, quizzes, and supporting resources, this “good fairy” interested the faculty and administrators of the course. Now that these curricular additions have been implemented in the curriculum for years and enshrined in the syllabus as small contributors to the final course grade, they have become enrolled as part of the course, durably incorporated into the system. The mobilization here is the ongoing efforts of students, faculty, and graduate student TAs to keep the “whole machine” running, and the wealth of resources like classrooms, worksheets, graders, websites, software packages, salaries, textbooks, etc. that are playing important parts in keeping the course running smoothly.

The instructor laments that “even as the coordinator of the course I’m not in a position” to start cutting things, to make significant “structural change”, as the “machine” within the department will continue to run, regardless of popular opinion. A new process of translation would be needed for the course to be mobilized differently, something that may eventually happen as class sizes at the local site continue to grow to unsustainable amounts.

To recall, translation was defined as the process wherein “an entity, human or nonhuman, becomes selected, enticed, persuaded and partially or fully changed in ways that mobilize it to join the network’s movements”\(^{27}\). In the excerpt from the instructor, the “machine” that is the engineering mathematics department has been persuaded to add a variety of curricular features to the basic course structure of Calc 3, changing the overall shape and organization of the actor-network that includes the interactions pertaining to the course. For instance, without recitations, the need for grading assistance, and lab courses, graduate students would need to find alternate means of funding their way through graduate school, affecting their actor-network circumstances significantly. By identifying the translations that have resulted in the current actor-network organization of the course and course activities, we can better see if the current consequences of past curricular decisions were intended or not. According to the instructor, “you add things to the list but you never take anything off”, at least not yet. Informed by this type of actor-network analysis, we hope to eventually suggest new translations to improve the experiences of all human actors involved in this educational system.

**Future Work**

The previous section is preliminary, as one way to look at the actors and the actor-network. While our analysis yields a basic understanding of the four moments of translation in sophomore engineering mathematics, we wish to dive deeper into the complexity of this nuanced educational system to understand the consequences of its actor-network organization in greater detail. Analysis of all collected data is ongoing and continuous as we piece together relevant actor-networks at fine levels of resolution from the various primary source accounts and information available. We see the value of arranging networks around categories of actors both human and non-human, in order to see how various elements are translated by one another: students, graduate teaching assistants, instructors, exams, textbooks, online networks, classrooms, chalkboards, etc. Simultaneously, we consider what it means to be on the periphery of these actor-networks, and identify cases from our data featuring fragile actor-network connections that are severed quickly, as with the student interviewees who chose to leave engineering after the
By mapping out these *actor-networks*, we hope to understand how different *actor-network* organization affects student trajectories through engineering, and how these *actor-networks* collectively contribute to maintaining, producing, and reproducing our educational system. In other words, we seek to identify the consequences of these *actor-networks* on our students and our structures, so we can be well informed in making recommendations and policies for change.

As our findings develop, we stay in close communication with stakeholders within our local university community. Part of the ‘trustworthiness’ or validity of our study involves the utility of our results for local application, the relevance of our research to those involved. Through follow-up interviews and informal meetings, we are working with the instructors at our site to ensure our findings will not be a surprise to them; instead they will be useful for initiating reforms. We are careful in offering constructive critiques of the contemporary situation as we see it, cognizant of the fact we are studying curricula that have been in place for many years and award-winning instructors who are truly passionate and committed to educating engineers, who are doing the best they can within the constraints of the current system.

Overall our data sources are diverse and varied: interviews, observations of humans and non-humans, artifacts from the past and present, etc. Reconciling the views of students and teachers on contentious issues including the ‘fairness’ of midterm exams and the ‘trickiness’ of specific problems requires our research team to see both sides of the issues, respecting the opinions of the participants involved. Combining these varied sources of data into a meaningful amalgam of sophomore engineering is a process of triangulation, as we look across time, people, and artifacts involved in the formation of *actor-networks*. We anticipate that our findings, though locally situated, will contain elements of engineering culture and society which have some level of generalizability to other similar settings of sophomore engineering at other institutions, in other places.

**Conclusion**

*Actor-Network Theory* offers a unique way of conceptualizing the social environments that envelop critical phases of undergraduate engineering. Recent publications in the field of engineering education have hinted towards *actor-network* perspectives, particularly a special issue of the *Journal of Engineering Education* focused on representations in engineering practice. Numerous authors have incorporated *actor-network* concepts in offering multiple perspectives on engaging engineers, and describing boundary negotiating artifacts in the context of design, while Johri, Olds and collaborators have introduced engineering educators to *actor-network* thinking by connecting the field to the learning sciences. The recent publication of the *Cambridge Handbook of Engineering Education Research* features a chapter by Roth which expands analysis on the subject of representations in engineering, further explaining the
importance of non-human elements like diagrams, figures, and equations as ‘what counts as knowledge in engineering’. Our work in studying the sophomore year of undergraduate engineering builds on this scholarship, adding here detailed explication of the four moments of translation and how these moments illustrate actor-networks of the sophomore year.

Looking at sophomore engineering from an actor-network perspective illuminates connections between objects/constructs and people that may be intentional or unintentional, chained to consequences like retention in engineering or the development of some skills at the expense of others. We utilize the ANT approach to look at social interactions and complexity that cannot be accounted for with an analysis of isolated factors. Moving from studying isolated interventions to heterogeneous connections in sophomore engineering gives us a lens through which we can investigate how new technologies (including nonstop online connectivity) are changing the organization of space and time for our students and their actor-networks. Simultaneously, we search for cracks in ossified educational practices that have endured unexamined for “years and years.” Taken as a whole, we seek to uncover the consequences of different actor-network formation and dissolution on the trajectories of sophomore engineers and provide informed recommendations for educating engineers.

References


