Becoming an Engineer: Toward a Three Dimensional View of Engineering Learning

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ABSTRACT

In this paper we develop an analytical framework we refer to as "Becoming an Engineer" that focuses upon changes occurring over time as students traverse their undergraduate educations in engineering. This analytical framework involves three related dimensions that we track over time: disciplinary knowledge, identification, and navigation. Our analysis illustrates how these three dimensions enable us to understand how students become, or do not become, engineers by examining how these three interrelated dimensions unfold over time. This study is based on longitudinal ethnographic data from which we have developed "person-centered ethnographies" focused on individual students' pathways through engineering. We present comparative analysis, spanning four schools and four years. We also present person-centered ethnographic case studies that illustrate how our conceptual dimensions interrelate. Our discussion draws some educational implications from our analysis and proposes further lines of research.

Keywords: ethnography, learning, student experience

I. INTRODUCTION

In this article, we argue for understanding engineering learning within a broader framework that we call "becoming an engineer." Whereas a focus on "learning" typically draws attention to changes in an individual's cognitive capacities, a focus on "becoming" draws attention to additional dimensions of change over time, and in particular, to a broader set of social organizational practices in which the engineer-in-the-making is embedded and through which she or he charts a course. We are seeking to capture both a sense of how a person makes oneself into an engineer and how one is made into an engineer as one traverses a pathway through both the formal and informal experiences associated with an engineering education.

A survey of the last decade of *Journal of Engineering Education* (JEE) articles about learning (1997–2007) cluster into three main types. First, basic empirical research articles on engineering learning typically have employed units of analysis and methods from cognitive science as applied to learning (e.g., Borrego, 2007, p. 4; Friesen, Taylor, and Britton, 2005; Thompson et al., 2005; Turns et al., 2005). Articles of a second type, also empirical, have made operational categories of learning for the purposes of evaluating the effectiveness of particular educational initiatives; these studies have typically used pre- and post-measures, often indexed to programmatic standards from ABET and similar organizations (Parsons, Caylor, and Simmons, 2005; Terenzini et al., 2001; Wiesner and Lan, 2004). Other studies of this second type have used measures of student satisfaction as proxies for learning (Olds and Miller, 2004; Porter and Fuller, 1998). A third type of article has been prescriptive, laying out programmatic directions for engineering student learning, but not exploring empirically how or what students learned (Dym, 1999; Pimmel, 2003; Schneck, 2001). Worth noting also is that "learning" itself as a topical focus was a relatively uncommon one for JEE articles until recently. In the first decade of JEE (from 1993 to 2002), only 6.5 percent of JEE articles used "learning" as a keyword, compared with "teaching" which appeared four to five times as often (Wankat, 2004).

What this review of JEE articles shows is the ethnographic approach to learning, and moreover an expansion to focusing on learning within the broader frame of becoming, is relatively distinctive in the context of research on learning engineering, although it is not without related precedents (Ambrose, Lazarus, and Nair, 1998; Courter, Millar, and Lyons, 1998; Foor, Walden, and Trytten, 2007; Hall and Stevens, 1995; O'Connor, 2001, 2003; Seymour and Hewitt, 1997; Stevens and Hall, 1998). The specific approach we have taken has been called *person-centered ethnography* (Hollan and Wellenkamp, 1993; LeVine, 1982, p. 293). This term highlights both our interest in how *individual persons* become engineers, and also that persons are always, and without exception, persons "in context." The methodological rationale for this approach, and one that distinguishes it from other approaches to learning in engineering research, is to get at the whole person's experience, or to "recover persons," as Richard Jessor (1996, p. 4) puts it:

> [t]here is frustration [in the social sciences] over the inability to *recover persons*—to retrieve their individuality—from the matrix of relationships that continue to be established among variables of scientific interest. The absence of a *person focus*, and the continued emphasis on relations among variables, has yielded a body of knowledge

> in which persons in all of their complexity—actors managing the uncertainties and vicissitudes of daily life—are difficult to discern…[O]ur normal methods…attribute causality to the variables…rather than to agents; variables do things, not social actors.

The persons we want to recover are engineering students moving through their undergraduate educations. In our view, students are too often treated as relatively homogenous fluids flowing through, and sometimes leaking out of, the so-called "pipeline," a metaphor about which we will have more to say later. These fluids/people are sometimes parameterized by variables like gender, ethnicity, or learning style (all helpful amendments to the homogenous imagery), but, even so, the course of their individual pathways and experiences as engineers-in-the-making remains relatively obscured.

We develop and exemplify a framework that maps changes in three dimensions over time to recover *persons* across pathways that are partially of their own making. The first dimension, *disciplinary knowledge*, is the one most traditionally associated with the concept of learning in the school aged years (Bransford et al., 2000; Bransford, 2007; Stevens et al., 2005). The second dimension, *identification*, refers to how a person identifies with engineering and is identified by others as an engineer. The third dimension of our framework, *navigation*, is one that focuses on how a person moves through the personal and institutional pathways as an engineer-in-the-making to be officially recognized in one or more ways as "an engineer," pathways that are cut along both official and unofficial routes.

The data from which we develop and exemplify our framework is longitudinal and ethnographic, based on a four-year study of engineering students, whom we have followed from their freshman year through their senior year. At one of the four schools, we have accompanied these students on their daily round during each academic year and have interviewed them regularly throughout the year. At all four schools, multi-hour ethnographic interviews were conducted with students during each of their four years; these interviews were conducted by colleagues at each of the partner campuses and by us at one campus. This paper draws primarily on data from the first campus (Large Public University), supplemented for the sake of ethnographic generalizations by analysis of interviews conducted with students at the three other campuses. These data are part of a larger multiple methods study of engineering education called the Academic Pathways Study (Sheppard et al., 2004).

These data support a variety of comparative and case study lines of analysis. These include developmental analyses, depicting how students change over the various nested timescales of becoming an engineer, and comparative analyses, both across individual students (Stevens, O'Connor, and Garrison, 2005) and across the respective cultures of engineering education on the different campuses (Stevens et al., 2007). Such comparisons disclose both important cross-school similarities and equally important local cultural variations in how young people become engineers, both in its meaning to them and in the socially organized practices and discourses through which this becoming process is managed by institutions.

The remainder of our article proceeds in four parts. First, we outline the three conceptual dimensions we use to follow the engineering students' educational pathways. Second, we exemplify the kinds of comparative and developmental analyses that are possible with these sort of data and framework, tracing some similarities and differences across the four years of some undergraduates' experiences and across four different undergraduate colleges of engineering. Third, we present two brief person-centered ethnographic case descriptions of two of our research participants to show how our three conceptual dimensions interrelate in an analytic description of particular lived pathways. Finally, we draw out implications for further research and for engineering education's practical initiatives.

II. Outlining Three Dimensions of Becoming an Engineer

A. The Development of Accountable Disciplinary Knowledge

Over the last half century, research on learning has shifted from a domain or discipline-general perspective of learning to a discipline-specific one (Stevens et al., 2005). During this period, much of the research on disciplinary knowledge that has informed engineering education has been conducted by cognitive scientists, whose leading conceptualization has been in terms of *acquisition* of disciplinary knowledge, based on characterizations of differences between expert and novice minds using a methodological approach that has come to be known as *the expert-novice paradigm*. This paradigm involves posing common laboratory tasks to "experts" and "novices" and then interpreting comparative task performance data, typically in the conceptual language of information processing psychology. In turn, these comparative analyses of expert and novice task performance license inferences about how disciplinary knowledge is progressively acquired by people over time. For example, a classic study in this tradition involved posing textbook physics problems to professors and beginning physics students and using that to infer a trajectory of disciplinary knowledge acquisition from two snapshots of task performance by researcher-designated novices and experts (Chi, Feltovich, and Glaser, 1981).

Our approach to disciplinary knowledge, while informed by the comparative logic of the expert-novice paradigm, differs in important ways (see Hall and Stevens, 1995). An *ethnographic approach to disciplinary knowledge* makes different assumptions than does the information processing tradition and the specific expert-novice paradigm about how people learn and about the nature of what it means to know or practice a discipline. One of the key assumptions of the expert-novice paradigm relevant to our purposes here is that it generally assumes that a discipline is a relatively stable body of knowledge that individual people progressively acquire. Under this view, the selection of a single common task posed to novices and experts in a laboratory setting may be treated as a trustworthy gauge of disciplinary knowledge acquisition. In contrast, a key finding of ethnographic studies of disciplinary knowledge is that distinctly different forms of knowledge are *counted* as disciplinary knowledge in different situations, at different times, and by different people (Hall and Stevens, 1995; McDermott and Webber, 1998; Stevens and Hall, 1998; Stevens, 2000). As a result, the assumption of a stable body of knowledge that is progressively acquired by members of a discipline is challenged. This is not to say that real and interesting differences are not found in expert-novice studies, but it does highlight a qualitatively different view of disciplinary knowledge in that ethnographic studies of disciplinary knowledge present a more disunified view of what it means to have and use disciplinary knowledge, finding greater variation in what individual disciplinary practitioners know and do. Most importantly, however, the ethnographic approach to studying disciplinary knowledge highlights the contextual variety of what counts as disciplinary knowledge, making it a requirement of studying disciplinary knowledge that differences in what counts are mapped over time and situation and that analysis attends to how research participants handle and adapt to these changing contexts of what counts.

We draw here on this ethnographic approach to disciplinary knowledge, focusing on what we call *accountable disciplinary knowledge* (ADK). We use this term to refer to actions that when performed are counted as engineering knowledge. knowledge. Familiar performance contexts of ADK in engineering education, like in other technical fields, are problem sets and exams. In contrast, problem sets and exams are not accountable disciplinary knowledge in the daily work of professional engineers or in most forms of occupational work. The concept of accountable knowledge is useful for an ethnographic study focusing on students' changing experiences and their understandings of them, because it helps us account for a number of phenomena we have observed in our data that we cannot make sense of with any single researcher-stipulated definition of what counts as engineering knowledge. For example, students in our study are confronted with different images of engineering knowledge across the many contexts they inhabit and over the four years of their engineering education careers; these include differences between early and late career coursework and differences between internships in professional engineering firms and university coursework. Students respond differently to these shifts in relation to both what they "already know" and to how they project their future as engineers. Thus, changes in what counts as engineering and how students respond to these changes are important elements in understanding how they become engineers.

B. Forming an Identity as an Engineer

A fundamental issue often overlooked in studies of learning framed in terms of knowledge acquisition is the formation of an identity as a particular type of disciplined person. Here, the particular types of disciplined people we are interested in are called "engineers." The importance of identity was reintroduced to learning research by Lave and Wenger's (1991) monograph, *Situated Learning*. This monograph drew upon an extensive body of ethnographic research in educational and other learning environments, including the work of Howard Becker and his colleagues concerning the development of identification with professions (Becker, 1972; Becker and Carper, 1956; Carper and Becker, 1957; Marshall, 1972). Becker's approach, which influences ours here, emphasized how would-be professionals understood themselves in relation to their anticipated professions and how these understandings changed over time. Lave and Wenger, and others taking related anthropological stances on learning (Holland et al., 1998; Packer and Goicoechea, 2000), highlight that learning involves more than the acquisition of skills and knowledge, but also involves changes in what types of people we become and in how someone understands him or herself in relation to a particular disciplinary practice (e.g., engineering). In this approach, who an individual is, that is, his or her identity, depends upon how he or she actively identifies himself or herself and is actively identified by others within the various social fields in which he or she acts, including friendships, families, universities, and professional contexts. Holland and colleagues clarified the distinction between the concepts of identity and self, arguing that the concept of identity is "double sided" (Holland et al., 1998; Skinner, Valsiner, and Holland, 2001); not only do one's own understandings help create and stabilize an identity (e.g. as an engineer), but so also do the ways that a person is positioned by other people and institutional practices. Identity in these formulations is understood as formed out of a double-sided process of positioning ourselves and being positioned by others. In this work, we are focused on two key issues: (1) how engineering identities develop over time, stabilizing within the double-sided process of specific acts of identification, and (2) how the differing forms of accountable disciplinary knowledge in engineering education, position people differently in terms of their identifications with engineering.

C. Navigating through Engineering Education

Most institutions, and nearly all educational institutions, present a series of "obligatory passage points" (Latour, 1987) through which people must pass in order to move toward official recognition as a particular something (e.g., engineer, doctor, married person). To have had conferred upon oneself the label of "engineer," that is, to become *institutionally identified* as an engineer, a person must, for example, be "admitted" to the college, "pass" a series of courses, and "complete" certain sets of requirements to "graduate." Therefore, navigation indexes one dimension of becoming an engineer that is conceptually distinct from accountable disciplinary knowledge and identification.

While navigation is a conceptually distinct dimension, it is related to identification and ADK in practice. After all, schools are places where successful disciplinary knowledge performances align with progressive navigation. In other words, the officially sanctioned way to navigate through higher education is by performing above some threshold on ADK, and distinction in displaying ADK nearly always means smoother navigation. However, the official route is not the only route, nor is a successful record of ADK necessarily assembled in just one way. Different students navigate differently through engineering, and these differences can be consequential not only for where they end up, but also for the duration of their undergraduate experience, the social networks they create, and the quality and substance of their identification with engineering.

To illustrate what we mean by navigation and its relevance to understanding how people become engineers, consider a story we heard during our fieldwork. We learned that fraternities keep "test banks" for particular courses. Since fraternities are enduring institutions, current members benefit from tests collected by previous members. Thus, students in fraternities have different resources than do other students for navigating the part of their educational careers involving "passing courses" and "getting good grades." The concept of navigation also gives us a way to talk about how other people and institutional resources play a role in a particular individual becoming an engineer or not. Finally, a focus on navigation gives us a way to talk about the importance of place and rites of passage (Turner, 1969) in an educational career. Our analysis shows that dramatic changes take place across critical transitions through obligatory passage points, such as the transition from being an applicant to being a member of an engineering department.

D. Integrating the Three Dimensions

These three dimensions of "becoming an engineer," while conceptually and analytically distinct, interrelate in practice. Indeed, these interrelationships are the source of much of their power as analytic tools. All engineering students can be seen as moving along each dimension at all moments in their educational careers, and movement along any one dimension can become consequential to becoming an engineer when intersecting with the other dimensions. For example, consider a high school student who is skilled at solving textbook math problems. This skill is an important part of ADK early in the engineering curriculum and certainly in being granted initial entry into an engineering program and so is potentially related to that student's becoming an engineer. In order for it to become related *in practice*, however, it is necessary that the student who has this potential ADK be identified as "engineering material," both by him or herself and by disciplinary representatives. This identification might then lead to navigational practices that start the student along the pathway to becoming an engineer: taking AP courses in math, selecting a university for its strong engineering programs, seeking a precollege internship, or speaking with counselors who are informed about engineering majors and careers. These navigational moves in turn might lead to further identification, as in recognizing a kinship with mentors or fellow students, as well as further development in terms of ADK, such as exposure to genuine engineering problems that are subsequently used to contextualize abstract textbook problems.

These three dimensions are intended to provide a general conceptual framework for understanding the processes of becoming an engineer. It is important to note, however, that the dimensions and their interactions are necessarily understood, first, as contextually specific, and second, as not predictable *a priori*. That is, in order to observe precisely how one is held accountable for disciplinary knowledge, or how one becomes identified (or not) with the discipline, or how one navigates an institution, it is necessary to observe these processes in practice and in specific sites of activity. Thus, our theoretical commitments to understanding development in practice have important methodological implications as well, in that they require an approach that is well suited for understanding processes and practices that are inherently contextually specific.

As we described earlier and elaborate on here, we adopted an ethnographic approach. This form of inquiry has a long history within anthropology and sociology and has seen a recent resurgence as social scientists have become interested in examining the situated qualities of human action and meaning making. Ethnography is a methodological approach that employs various methods, including observation and regular conversation with study participants in and around their routine activities in order to describe and understand specific social worlds in terms of viewpoints of participants. This commitment is of course shared with other approaches, including survey research or research using structured interviews, and we acknowledge the usefulness of such methods for certain purposes. As Becker (1995) points out, however, ethnography is for several reasons particularly well suited for understanding actors' perspectives. Four reasons are particularly relevant here. First, using ethnographic methods keeps our developing understanding of a social world grounded in participants' meanings. This allows, as Becker maintains, for fidelity to the experiences of "members." Second, using ethnographic methods leads us to remain open to seeing unanticipated significance in participants' activities. Because we proceed from members' meanings to theoretical generalizations about their social world, rather than starting with a model of the world that is then "tested," our groundedness in the data allows meaningful patterns to emerge that might not be expected by an *a priori* theoretical framework. Third, our perspective involves a recognition that much of the meaning of everyday life is found in routines that are enacted by participants, routines that are not necessarily available to conscious reflection by participants. Finally, a general heuristic of ethnographic research, especially when the focus of study is institutional experience, is that there are both official and unofficial practices, those sanctioned and recognized by institutions and those that members create, adapt, and often obscure from the official. Ethnographic work is especially attentive to the unofficial because as ethnographers have repeatedly found, much of the real action of learning and institutional life can be found there.

III. Across Four Years and Across Four Schools: Similarities, Differences, and Changes Over Time in Accountable Disciplinary Knowledge, Identification, and Navigation

In this section we exemplify some of the comparative findings from our study across and within schools and over the years of an undergraduate engineering education. We focus in turn on similarities and differences, across four years and across the four schools, in our three dimensions of becoming an engineer: Accountable Disciplinary Knowledge, Identification, and Navigation.

A. Accountable Disciplinary Knowledge

We begin with similarities found among the engineering students across all four schools in accountable disciplinary knowledge. One of these similarities involves changes over the four years in the basic trajectory of what counts as disciplinary knowledge. Changes in ADK included: (a) types of events for displaying knowledge (e.g., lecture, laboratory, or project), (b) types of problems to be solved, including the locus of responsibility for finding and posing those problems, and (c) students' relationships to one of the fundamental objects of engineering, data. These changes over the four years were dramatic enough that it could be argued that distinct and only partially relatable activities, or what Redish and Smith (2008) call "epistemic games," counted as engineering for freshman and seniors.

A structuring principle of the educational experience across schools was the "prerequisite," that students could only succeed in certain courses with a base of knowledge from other, more "basic" courses. Subsequent courses typically assumed that students had mastered the prerequisite material, although students often told us that they came to comprehend the material from a prerequisite only after completing subsequent courses for which this material was an assumed resource. Prerequisite courses were almost exclusively lecture-based, sometimes with a complementary lab component. Tests were administered to individual students to assess mastery, and course grades were largely based on the exam scores, sometimes supplemented by homework, online quizzes, or lab reports. Generally student work was individually evaluated, although students commonly asked peers for help on difficult homework problems and completed lab reports with partners. Instructors assigned text-based problem sets that related to a lecture topic and consisted of well-defined problems, each with a single, correct answer. In prerequisite courses with labs, the operative assumption governing lab assignments was that there was one right answer or rather one right recipe to follow to produce the lab's expected result. In sum, students were expected to perform planned experiments, with known results, rather than to design experiments.

Changes in ADK became visible as students began taking upper-level courses in their majors. Increasingly, projects and labs became the foci of coursework and laboratory work was no longer built upon following a recipe to reach a single, expected result. As a junior taking upper-division classes at Large Public University, Anke formulated the difference in this way:

> The lab is a lot different, because you have to come up with your own procedure. You don't get like just a handout and do it. You have to come up with all the theory, the equations, and how you're gonna perform your experiment, and then actually do it, so…it sounded like it was gonna be a lot of work and it was gonna be really hard to come up with—define the problems and come up with the solutions, but it's actually not that bad, so and I think it's a funner lab cause you actually come up with the procedure and do it so, instead of just reading out of the book and following steps.

In general, the highly structured problem sets typical of early courses gave way to more open-ended problems in upper division coursework. According to the assumptions of prerequisite courses, solutions for open-ended problems were meant to involve application of skills of skills and knowledge developed in prior coursework, although we observed students having great difficulty in applying knowledge in this way. Students were often expected to use a wider range of resources to solve these problems, and problems came packaged in new forms, as in fictive professional scenarios. For example, one group of students received an assignment in the form of a memo that began: "Your company…has just been awarded a contract to build a sophisticated avionics, control, and data acquisition system." In this example, the problem was not prescribed; it had to be identified and represented *as an engineering problem* from the text of the memo before students could set about the business of solving it. Whereas problems in the early years simply appeared without an apparent human source, problems in upper level courses increasingly introduced agents to the scene, albeit usually fictive ones, in the form of clients for whom the problem mattered. It was also increasingly expected that some of the resources to solve the problem would need to be found, rather than given in the textbooks. This shift meant that students sometimes spent significant time researching an issue before they even began work on solving it. Written reports explaining their solutions and justifying their approach became increasingly expected. Because these problems were understood to have multiple solutions, justifying a particular solution amidst a set of tradeoffs became important. Thus, communicating and justifying problems and solutions became new forms of ADK at this phase of the educational experience.

The shift to more open-ended problem solving and the accompanying shift in ADK were sources of frustration for some study participants, seeming both an abrupt and a radical departure from prior understandings of problem solving. For example, Adam, a senior at Large Public University, was asked about his capstone design project and said that he was "intimidated" by the "really open-ended stuff." Max, a senior at Technical Public Institution, also talked about the open-ended work that he was assigned senior year and said this work made his classmates nervous because they were no longer looking for "one right answer."

Another common shift in ADK from the early to later undergraduate experience is that the units of performance and assessment increasingly shifted from individuals to teams. Teamwork was not entirely absent from early coursework and at Technical Public Institution students were required to take a sequence of courses in the first two years in which students worked in project teams, but teamwork seemed to take on a different meaning for students at all the schools later in the undergraduate years; at this point, teamwork's apparent centrality to further engineering work required further adjustments in students' understanding of what counted as engineering knowledge. For example, Leslie was a senior at Technical Public Institution who reported annoyance at other members of her capstone design team "just slap[ping] something together" and not "doing their best." She spoke as if in one of these teammates' voices and then in her own, "Oh, this project's not going to take very long, let's spend an hour, when we should be spending 20 hours on this kind of thing. And it was so hard." At Large Public University, a senior named Joe told us about the challenge of being positioned as the sort of person that Leslie complained about in her team project. Joe told us about how at the end of a quarter he received an e-mail from the professor for a course in which he participated in a team project. The professor informed Joe that his teammates, based on a peer assessment document, had found his participation lacking. The professor suggested that the Joe "transfer some of his points" earned as part of a collective grade to the other students. Joe, who described his less than complete participation as an outcome of being sick, agreed to transfer the points, thereby lowering his grade. He concluded, "the quarter kind of sucked."

Another shift in ADK involved the role of data in students' work. Problems in pre-engineering courses routinely required work with representations called "data," but generally these data were provided in the problem itself. In their upper level classes students were expected to generate their own data, either through research or experimentation. These new expectations regarding data significantly extended the time spent completing assignments. From pour columns in a chemical engineering lab to a series of runs in a wind tunnel in an aeronautical lab, students were progressively exposed to new tools for collecting and new methods for analyzing data. Where they ended up at the late stages of their educational careers was a far cry from the data-given-in-text-of-the-problem days of the prerequisite courses.

A related issue involved the expansion of considerations that were valid in posing and solving problems. Observations of a senior design project suggested that problems worked under the "perfect world" conditions of problems in prerequisite courses, "assuming Newton always holds," as one electrical engineering (EE) student described it, did not prepare students to deal with the more "real world" conditions they faced in senior-level courses. For example, in a chemical engineering senior design class, hydrogen containers designed by a student team fulfilled the assignment well within a narrow engineering science perspective, but were deemed inadequate solutions from a wider perspective. The TA approached one team member, said that the containers were a great idea, but asked, "Will they fit under a highway over pass? What about on a train?" The student was surprised by these questions in her senior year, having never been asked to consider things like transport.

Another shift in ADK involved sources of relevant know-how in senior-level work. At this level, instructors began expecting students to augment the resources used to solve problems, going beyond what they were supposed to have learned in previous coursework with resources outside the official curriculum. This was the case with some programming languages like C and even more so with software applications students were expected to use for design, modeling, or symbolic algebraic manipulation such as AutoCAD and ASPEN. For example, Louise, a third year EE student at Urban Private University, reported needing to use MATLAB software to successfully complete her final exam in a class, though this software had never been taught in a course in her college. She was simply required to know it and had to learn the software outside of the official curriculum.

Another shift in ADK involved changes in the role of "teachers" in coursework. In upper-level courses, professors adjusted the degree and type of assistance they provided to students, becoming increasingly "hands off" in their management of student project groups. For example, in a chemical engineering senior design project class the instructor announced with three weeks left in the quarter that he was shifting more responsibility to students. Where previously he had volunteered critiques and questions about designs and implementations presented during weekly progress reports, he began expecting the students to identify problems with their own work. Instead of regularly posing questions to students to test their understandings, he now expected students to ask him questions that would improve their projects. Whereas previously the students relied upon their instructor to point out the flaws in their work, now the responsibility fell to them, shifting the locus of responsibility for identifying and diagnosing problems.

B. Identification

Another type of similarity across students at the four schools involved changes in identification. We will touch on this briefly since this has been our focus elsewhere (Garrison et al., 2007; O'Connor et al., 2007; Stevens, O'Connor, and Garrison, 2005; Stevens et al., 2007). One of the most evident changes over time across the schools is that students demonstrated increasing solidarity with other engineering students and increasingly reported differences between themselves and other college students (Stevens et al., 2007). At Large Public University this sense of shared identification was clearest in changes in students' language as they crossed the threshold from the "pre-engineering" designation to formally recognized "engineering student." Students started referring to themselves and other engineers as "we" and non-engineering students as "they." This we/they language was present in Technical Public Institution and Urban Private University students even earlier. At Suburban Private University this "we" versus "they" distinction showed up as a widely used distinction on campus between "techies," who studied engineering or other technical subject matter, and "fuzzies" majoring in social sciences, arts, and humanities.

Another more tangible change in identification practices common across schools, and one that paralleled the solidification of the we/they language, were reports by students of new access and new habitations of engineering-specific cultural spaces. Students were granted "keys to the clubhouse," not just metaphorically as in Margolis and Fisher's evocative phrasing (Margolis and Fisher, 2002), but literally. At Large Public University, for example, students acquired access codes to enter special labs and passwords for closed wireless networks in their engineering buildings. Once admitted to the spaces, students enjoyed lounges with access to snacks and stores that stocked supplies for engineering coursework. In a "survival guide" presented to new computer science and engineering majors at their orientation at Large Public University, one section of the document was devoted to working very late. This section included information about where in the building to "take a 4:00AM nap," how to get into the building after hours, and where in the building one could get caffeinated beverages. Students at the other three institutions also reported similar kinds of intense habitation of engineering-specific cultural spaces. At Urban Private University, students talked about being "down the hill" from the rest of campus and spending most of their time in the engineering building, effectively isolated from other people and places on campus. Some Technical Public Institution students reported that the locus of their activities was their department's computer lab. As one civil engineering student observed, "Pretty much whenever I'm on campus in between classes I'm in the lab working on either computer-aided engineering or senior design." Suburban Private University engineering students described forming study teams that "stick together," studying, eating, and spending extraordinarily long hours together. One Suburban Private University EE major joked that they spent so much time in the EE building it felt like they lived underground and had come to "hate sunlight."

The forms of identification discussed thus far largely concern how individual students and groups of students identified with the discipline. We made the point in the introduction that identity is "double sided," that is, who an individual is, his or her identity, depends not only upon how he or she actively identifies himself or herself, but also upon how he or she *is actively identified by others* within the various social fields in which he or she acts. In the remainder of this section, we will present comparative data across the four schools concerning what it means to be *in* engineering, or *not in* engineering. This is a key aspect of a "double-sided" approach to engineering identities; we have found that differences in how institutions officially identified students as engineers had profound effects on students' identification of themselves as engineers and on their futures and commitment to the field.

Here we begin by comparing two campuses in our study where these differences are most stark. At Large Public University about 90 percent of students applied to the College of Engineering the summer before junior year and, if admitted, enrolled in the College as juniors. Prior to being admitted to the College of Engineering, most students' majors were classified as pre-engineering, which allowed students to show intent to major in engineering and allowed the college to track these students. Classification as pre-engineering meant that students received listserv messages with information about scholarships, special courses, admissions requirements, and advising, all prospectively oriented to their futures as potential engineers *pending admission*. At Large Public University, a small percentage of students were admitted earlier than their junior years, as sophomores (7–8 percent) or freshman (about 2 percent). Suburban Private University is an elite private university that shared this same basic timeframe as Large Public University for students to enter engineering as majors, after their sophomore year. However, the key difference is that at Suburban Private University students *declared* their majors rather than going through a competitive application and admissions process. Thus, there was a form of gate-keeping at Suburban Private University as at Large

Public University, but it was consequentially different for the experiences of the students. At Suburban Private University students effectively chose engineering, or did not, whereas at Large Public University, engineering chose students, or did not. This difference manifested itself in how students talked about themselves in relation to engineering.

Students at Large Public University talked and worried a lot about whether they would "get in." For example, Suzanne at Large Public University talked about the consequences if she were denied admission to the very competitive bioengineering major: "All these engineering classes [are] going to be a waste if I don't get in." In general, students at Large Public University faced a daunting investment risk in their first two years; they were required to invest a great deal of their college coursework in engineering pre-requisites and yet faced the possibility that they might not cash out this coursework as engineering majors if denied admission. As a result Large Public University students tended to display anxiety, uncertainty, and ambivalent commitment relative to a future in engineering before they were admitted. Suburban Private University students' talk did not reflect a sense of risk, but of choice and opportunity. The contrast is clear in what we heard from Emma, a sophomore at Suburban Private University, who said laughing, "I should declare soon. Yeah, so but I haven't." Grace, in her sophomore year at Suburban Private University said, "I haven't quite declared, but, um, yeah, product design and going that route." Students at Suburban Private University also mentioned that they seemed more "goal-oriented" after declaring their majors. This move to a more goal-oriented stance was largely on their timeline and in their hands whereas it was in the hands of admissions processes at Large Public University. At Large Public University, students' talk changed once they got into engineering, but for most, getting in remained a contingent reality, one managed on the institution's timeline and, from the perspective of the students, the institution's mostly opaque standards (Garrison et al., 2007). Additionally, students at Suburban Private University also had an option of pursuing a co-term, which was a fifth year master's degree; this could be in a major other than engineering. We raise this point about co-terms to show that in comparison with Large Public University, Suburban Private University students had discretion and choice at both ends of the engineering major, making the investment in engineering at Suburban Private University, however intellectually and practically taxing was the coursework itself, a safer longer term investment than it was for students at Large Public University. In sum, although the time in calendar years was essentially the same for becoming engineering majors at Large Public University and Suburban Private University, the cultural differences between the two university environments and the ways that participation boundaries of the discipline were managed at each school had profoundly different effects on the students at each school who identified as potential future engineers.

It is also instructive to consider the two other schools in our study, Technical Public Institution and Urban Private University, to further exemplify how comparative ethnography can disclose relations between individual and institutional experience. At Technical Public Institution, a small engineering college, students were typically admitted as entering freshmen, which granted engineering students status as future engineers making them part of "the club". This cut both ways at Technical Public Institution, because those students who found themselves not wanting to be engineering students after some time at the school, faced the choice of not simply leaving the major, as a student at Suburban Private University might with a soft landing in another waiting major, but leaving the school. Technical Public Institution itself was in essence all about engineering. At Urban Private University (a historically black comprehensive research university), the risks were of a different kind than at Technical Public Institution and Large Public University. Some students felt compelled to leave engineering, even though they identified with it, because the stringent grading standards might lower grade point averages (GPAs), threatening a scholarship that enabled students to be at Urban Private University in the first place (Engerman, Fleming, and Williams, 2006). In summary, differences in the local cultures at each of the four schools were associated with complex and *different* relationships between being at the particular university and being in engineering. At three of the schools (Technical Public Institution, Urban Private University, and Large Public University) the investment risks of choosing engineering at that school were clear enough whereas at Suburban Private University the investment risks seemed significantly mitigated.

These last points regarding the "investment risks" of choosing engineering point us to a third dimension of becoming an engineer, that of navigation.

C. Navigation

The greatest differences we found in our study, across students and schools, were in the dimension of navigation. The story of any student's actual navigation is of course a mix of official well-marked routes and unofficial routes. For example, in an extended comparison of cases, in the next section we show how Simon, at Large Public University, takes an unofficial route into engineering whereas his contemporary, Jill, found herself leaving engineering after trying to follow the official route.

Not only are there unofficial routes, there are unofficial strategies for making it through official routes. For example, Darrell, a Suburban Private University student, explained how he took a required physics course at a nearby state university in order to avoid taking the class with a physics professor who had a very bad reputation among engineering students. Darrell noted that many of his Suburban Private University peers in engineering used similar navigation strategies to avoid taking classes with other notorious professors, including taking courses at a much lower status community college. At Large Public University, a student named Johnny took a detour by taking courses that did not count for the major and that he knew would delay completion of his degree but that he believed would better prepare him for those required courses.

The differences we found in navigation among students were clearly related to what might be called the *navigational flexibility* on each campus. Among our schools, as we have discussed earlier regarding the relative investment risks of pursuing engineering at the four campuses, Suburban Private University provided the most flexibility to its students. For example, Emma was a student at Suburban Private University who stated that she had plenty of time to take classes outside of engineering. When asked how she decided what classes to take, "Um I think a lot, some of the classes that I have to take, it's—most of em, I just pick em because I think they're interesting." In contrast, Bryn at Large Public University, almost left engineering because her personal intellectual goals compelled her to take advantage of the broader undergraduate experience, to take courses to further her development as a human being outside of engineering (Stevens, O'Connor, and Garrison, 2005). In the end, Bryn stayed in engineering and resolved the personal dilemma of completing coursework and following her other personal development goals by staying on campus for an extra year of undergraduate coursework. Bryn needed to make this compromise because at Large Public University, as at Technical Public Institution and Urban Private University, navigational flexibility was limited, because such a great percentage of a student's college experience was prescribed by engineering and prerequisite courses in a more or less set sequence. In addition, other logistical features further limited navigational flexibility. For example, at Urban Private University, students said they had to follow their departments' recommended plan of study because required courses were often taught only once a year. Shermont, a junior at Urban Private University, explained it in this way, "Some classes are only offered like in certain semesters. If you miss your class, then you got like a whole year behind". Similarly, Max, a fourth year Technical Public Institution student, reported not wanting to "get off the flowchart," which showed what courses students were expected to take and in what semester. Max said that "if I got off the flowchart and like dropped a core class, I'd struggle in another class."

In addition to observing great differences across students in how they navigated through and sometimes out of engineering, we also found some similarities in how students at each of the schools navigated across the years of their undergraduate experience. At three of the four schools, students' involvement in non-official activities, even those related to engineering (e.g., Society of Automotive Engineers race car competitions and engineering clubs) decreased as they moved through their years of their engineering educations (Stevens et al., 2007). This decrease in participation at Large Public University had a particular timing in many cases, with students sustaining their extracurricular activities as they approached their application to the major. Once accepted to an engineering major, a number of students steadily dropped these "extra" activities from their routines. Seemingly, they had served their purpose. The exception to the rule of decreasing participation over the years was at Urban Private University, where nearly all of the students talked in interviews about maintaining their involvement in these non-coursework activities. While Urban Private University students may have held different reasons for sustaining this participation, many reported believing that participation in certain clubs would help in networking and thereby future employment in the profession following college.

IV. Toward a Three-Dimensional Account of Becoming an Engineer: The Cases of Simon and Jill

In this section, we illustrate our three dimensions of becoming an engineer using two short person-centered ethnographic case studies of Large Public University students Simon and Jill. Simon's case is a rich and complex one, but no more than any of the other students participating in our study. Like many of the Academic Pathways Study participants, Simon located the origins of his interest in engineering in his childhood. An early friendship played a role in nurturing this interest. The father of a childhood friend was a professor in one of Large Public University's engineering departments. Simon participated in various activities related to his interest in airplanes with this friend and his father, Professor Kraft. For example, when Simon was in the first grade, Professor Kraft started a model-airplane-building club in which Simon and his friend, the professor's son, participated. This activity was of great interest to Simon, who was fascinated by "things that went fast" and liked watching planes take off and land at the airport. Simon also told of how, as the boys were growing up, Professor Kraft often took them to campus and showed them his department's research labs, including a mechanical stress testing facility. So later, when Simon applied to Large Public University as a senior in high school, he was already quite familiar with many aspects of the university and its engineering programs, including the specific program in Professor Kraft's department to which he hoped to be accepted. Indeed, part of his reason for applying was the familiarity he had developed through his longstanding association with Professor Kraft. And Professor Kraft continued to be a resource to him through this process, reading over and commenting on his application to the university and introducing him to the head of the department and the department's admissions staff. Simon's interest in engineering was like many students, partly rooted in his childhood. Unlike other students though, Simon's interests were integrally connected to and "sponsored" (O'Connor et al., 2007) by a representative of the institution in which he eventually came to pursue these interests.

Simon was not admitted directly into an engineering major and began as a designated "pre-engineering" student with possible admission to a department somewhere in his future. His freshman year in pre-engineering proceeded in mostly typical fashion; he took the usual prerequisites, endured courses in large lecture halls, attended chemistry labs, and the like. His GPA of about 3.0 at the end of his freshman year was well below what he took, from the word on "the street," to be the 3.8 "cut-off" for early admission into the department. So despite his strong desire to be "in" the major, he opted not to apply early but to try to raise his GPA to the 3.4 that he thought of as the "bar" for regular admission after his sophomore year. He saw himself at this point as an "average" engineering student, and while he planned to work hard to bring his GPA up the following year, he was at the same time beginning to consider other options, including transferring to a different school, or even switching out of engineering altogether. He talked about music as a possible alternative major. This kind of consideration of other possibilities was another way in which Simon's experience was typical of pre-engineering students at Large Public University; the withholding of actual belongingness to engineering in the pre-engineering years was clearly associated with a less than complete identification with a future in engineering.

While much of Simon's first year experience was typical, there was a difference that turned out to be crucial: Professor Kraft's strong recommendation helped Simon in the latter half of his freshman year to land a coveted job in the very testing facility that he had visited as a child. This job proved to be pivotal in Simon's navigation through engineering as well as his emerging identity as an engineer through the remainder of his time at Large Public University. Many other pre-engineering students worked part-time in jobs unrelated to engineering; movie concessions, child care, and retail were just a few of the outside jobs held by APS participants. In contrast, Simon worked at least fifteen hours a week, sometimes more, in the testing facility during the academic year and worked fulltime during summers. Simon, along with other members of the facility crew, was involved from the start in all aspects of the tests conducted in the labs, from fabrication and changing out of parts, to monitoring test runs, to collecting, compiling, and interpreting data. And since the lab was used both in the department's curriculum and was also hired out to local and national companies for testing of designs, he was in regular contact with a wide range of clients, including not only more advanced students but also experienced professional engineers.

Through these contacts Simon began over the next year to develop an understanding of possible futures and to increasingly identify himself with these futures. His position in the testing facility offered him multiple "horizons of observation" (Hutchins, 1995) on the different career stages and types of engineering work in the department and the discipline. From recent Large Public University graduates who managed the testing facility, as well as from more advanced crew members, he was able to gain insight into the future coursework in the major, including which courses to take and when. From his role in running tests of junior lab courses and senior capstone design courses (courses he would not take as a student until years later), he was able from early in his studies to gain knowledge of the general shape of the work he himself hoped to be doing in a couple of years. He himself was quite aware of this trajectory, telling us, "There's stuff that I'm learning now…that I'm supposed to be learning in my junior and senior year of college."

From the professional engineers coming through the lab he was able to begin to imagine a professional future for himself. For example, he learned of differences between the nature of work in small and large companies, and talked during his sophomore year about his desire to work at a small company. He had watched engineers from a large company do testing in the lab, and saw their work as so highly specialized that no one else could take over in the case of the absence of one team member who had worked on a specific part. Similarly, Simon also learned of a distinction between design and test engineers, and sensed that he would prefer to be a design engineer. He saw being a designer for a small engineering firm as requiring a more complete understanding of the design process, whereas larger companies required specialization that could prevent an intimate and comprehensive understanding of design.

In these ways Simon's work in the testing facility was leading to a *personal* orientation toward the profession, an important part of developing an identity as an engineer. As we have noted, though, identity is a double-sided phenomenon involving *both* an understanding of oneself in relation to a social world *and* recognition, that is, identification, by relevant others as belonging in that social world. During his second year at the lab, while highly identified personally with the discipline, Simon had not yet moved through the obligatory passage point of official recognition as an engineering student, since he had not yet been admitted to the department. Importantly, he had not been successful in raising his GPA from the 3.0 he had earned during his first year. In fact, a 2.7 average during the first term sophomore year had actually lowered his GPA, and it was well below the 3.4 average that common wisdom told him was important for admission to the major. Simon's GPA now ranked 13th out of the 16 students in our APS ethnography cohort at his school. Simon faced a crucial navigational dilemma: Could he carve out the time to raise his GPA while still continuing to take on substantial hours and responsibility in the testing facility he so identified with? Or should he try another route into the major?

The dilemma was highly consequential for Simon. He had not yet demonstrated his ability to perform well enough on the tests of institutionally recognized accountable disciplinary knowledge that constitute the GPA. Other disciplinary knowledge that he was developing and displaying through his work in the lab and through another research project with another professor in the department was not knowledge he was accountable for displaying, at least not officially. That is, there was a much less clear-cut path from this knowledge, however relevant it might eventually become in the work of a *practicing engineer*, to institutional recognition as an engineering student—a dilemma indeed. Was Simon going to become an engineer? And if so, by what pathway? Would he move into a less preferred engineering major after all or even into music? Would he transfer to another school? The answers to these questions were by no means clear during and even through the end of Simon's second year.

Throughout this phase of his educational career Simon sought advice from many on how to resolve this dilemma, including turning again to Professor Kraft. As he considered his options he came to see his various non-curricular involvements as potentially strengthening his dossier in the eyes of an admissions committee who might favorably advance his candidacy for admission. These elements of the dossier included that he had conducted research with a professor in the department and had received a recent promotion to a leadership position in the testing facility. He had gained considerable personal familiarity with many professors in the department, both through his association with Professor Kraft and through his work in the testing facility. Based on the information he gathered here, Simon placed a key navigational bet (Becker, 1960); he was staking his claim on his work in the testing facility and decided to maintain his heavy responsibilities there.

The summer before his junior year Simon completed his application for admission, stressing the relationship between his experience and performance in the lab and his potential for success in the program. His application was successful. He had thereby gained formal institutional identification as a major in this department. As he took more upper-level courses in the department he expressed increased confidence in his abilities and knowledge, relative to his department cohort. His GPA rose significantly and, no longer identifying himself as an average student, he told us that his schoolwork was consistently graded among the top quarter of his class. At that point in his studies his experience from the testing facility began to become accountable disciplinary knowledge in his coursework, and Simon told us that he suddenly felt more advanced than many of his fellow students, excelling in classes and labs. This was a clear shift from his reported sense of his own position as a freshman and sophomore, a shift that seems occasioned by the context of accountable disciplinary knowledge changing within the institution and perhaps his improved performances on assessments now that he was officially identified as an engineering student.

This sense of increasing mastery and distinction grew for Simon through both his junior year and the first part of his senior years, culminating in his capstone class, where the knowledge he acquired in the testing facility over many years was key to the success of his team's project. He took charge of and became a key consultant for the tests that were conducted in the testing facility. Because of his knowledge of lab operations he was able to interpret the final data and how this affected his team's design.

Not only did his classmates from other sub-teams seek him out for questions about their work, but also the instructor, who worked for a large engineering firm, consulted with him about interpreting the data coming from the testing facility.

Beyond people at school recognizing his talents, people in the field at large did as well. At a job fair in Simon's junior year he stood out enough, both with his work in the lab and in his increasingly strong performance in his coursework, to earn a prestigious co-op with a government research lab. He viewed the co-op as not only an opportunity to gain valuable experience, but also to provide a possible pathway to a prestigious job in this government research lab after he graduated. The co-op also cast him among an elite group of students in this discipline nationwide, and furthered his identification with and by the field. He even had information about his co-op in a prominent spot on his Facebook page and included a picture he had taken with a famous person from the field as his avatar on that page.

As we write this now, some four years after we first met him, Simon is a fifth-year senior preparing to complete the final coursework toward his degree. While he has taken longer than typically expected, this was not because of difficulties encountered in the curriculum. Rather he deliberately delayed his graduation in order to serve additional tours at the co-op. He is now on the verge of becoming not only an engineer but also a highly respected and competent engineer in the discipline of his childhood passions.

Simon's case is useful in illustrating how our three dimensions intersect in one student's pathway toward "becoming an engineer." Looking back, it's possible to view Simon's success as the unfolding of the more or less straightforward trajectory of an intelligent and motivated student who followed his interests until he ultimately became recognized for his strengths. But while this understanding is possible, we think that such a view would be quite misleading, in that it backgrounds the contingency of his path and the extensive organizing work, by Simon and others, that shaped it at every point along the way. We can develop this point further by very briefly considering the pathway of another student, Jill, who also started at Large Public University with strong interests in the same discipline in which Simon was interested.

Jill's high school math and science grades were very high, but as a first generation college student she had little of Simon's social and cultural capital (Foor, Walden, and Trytten, 2007). Despite identifying herself early on as both a strong student and a future engineer, her vision of college and professional work and navigational routes through these was much less clear than Simon's. This was consequential for her. Hoping for early admission into the major, Jill loaded up on science and math prerequisites early on, despite navigational strategies that suggested she do otherwise, strategies both "unofficial" ("word on the street" was not to take the five-credit physics and chemistry courses at the same time) and "official" (the sample departmental curriculum was structured specifically to avoid taking these together). This same term, in addition to physics and chemistry, Jill, who had officially demonstrated ADK in calculus through credit received for courses taken prior to entering Large Public University, also took an advanced math course, differential equations. This course was not required for early admission, and meanwhile most of her peers were taking a lower level course in the calculus sequence. Her grades in each of these courses suffered. Despite faring poorly in differential equations with a grade of 1.9, she continued with matrix algebra, the next course in the math sequence, rather than retaking differential equations or even for the calculus sequence. She gave several reasons for this decision, including that she saw herself as a good student who relished a challenge; she continued to hope for early admission; and she was concerned about difficulties in continuing with the sequence later. On this last point, she told us, "If I don't do it now, I'll forget all my math, and I don't want to build all that up again, so it's just good to carry that on." It is noteworthy here that Jill had no contacts either in the specific department for which she was aiming or in the College of Engineering more generally to whom she felt she could turn for advice about her situation. Instead, she mostly relied on information from friends in making decisions about her coursework.

Jill's freshman GPA reflected her difficulties in class. Unlike Simon, though, she saw no alternative path into the major other than a high GPA (rather than working in a job related to the field as Simon did, Jill worked part time as a lifeguard). She redoubled her efforts along the GPA route, organizing weekly study groups and seeking tutoring and advising at a minority student center that was independent of the College of Engineering (albeit noting that the advisors seemed unfamiliar with the engineering departments). But by her second year, increasingly stressed, her identification of herself as a good student and future engineer was weakened, and again unlike Simon, she had no sponsor in the department identifying her as a good candidate for the discipline on other grounds. Despite her efforts, Jill's GPA after sophomore year was 2.8 (still, we would note, just 0.2 lower than Simon's, and higher than other study participants who were admitted to engineering programs). Lacking a suitable dossier to argue for her qualifications to be admitted to an engineering program, or even an awareness that this might have helped, Jill opted not to apply and instead switched to a business major. She went on to excel in this new major. In business, she quickly raised her GPA and received an award at a national design competition as a key member of an interdisciplinary team comprised of business and engineering students.

Despite her eventual success in her new major, Jill is a good example of a student who was, in Seymour and Hewitt's terms, "more pushed than pulled" out of engineering (Seymour and Hewitt, 1997, p. 292–293); she was "weeded out," largely unwillingly and under the duress of an institutional deadline, after a lengthy back-and-forth process of grappling with her mutual fit with the discipline. Seymour and Hewitt's account is offered against an overly individualistic view of why students switch out of STEM majors. That is, "individual ability," or presumed lack thereof, is in almost every case insufficient as an explanation of why students switch; rather, they argue that it is essential to look at institutional structures and processes to develop a full account of why students leave. Our work supports this claim, Jill being a case in point, but also extends the point in arguing that individualist explanations are equally insufficient for explaining why students *succeed*. Simon did not flow through a "pipeline" that Jill leaked out of; rather, an entirely unique and highly contingent pathway was constructed, by Simon and his consociates, that actively *pulled* him, but not Jill into the discipline.

V. From Pipelines to Pathways: Implications for Engineering Education and Further Inquiry

We consider the work reported on here something of a rescue and recovery mission. We are seeking to recover the people trapped within "the pipeline." The pipeline metaphor has certainly been useful for showing that, in the aggregate, the flow into and flow out of technical fields like engineering are out of balance, certainly with respect to women and under-represented minorities and probably, were we to look more closely, with respect to other important dimensions of diversity. Now that this general pipeline message is clearly established, we believe the metaphor does more harm than good and should be honorably retired.

The problem with the pipeline metaphor is that the metaphor's component parts seem to commit its users to a homogeneous view of people/fluids passing through the pipeline and to a view that the dynamics of flow-through can be established according to some formula. Our person-centered ethnographic studies of engineering students moving through their undergraduate careers convince us otherwise. Even within most engineering education programs and certainly in three of the four we studied where navigational flexibility was quite limited, college students still navigated through engineering in ways that display huge and consequential variation. They follow official routes using unofficial strategies and they make and follow unofficial routes. There are big differences in how students navigate and small differences, like a decision to take a more challenging course one quarter, that lead to big differences in whether a student stays or leaves engineering.

What holds the greatest number of students to pathways through engineering is a question we are not prepared to answer nor are we sure this is the most productive way to frame the question. Our work leads us away from a singular concern for the numbers and percentages of "types" of students who enter, stay, or leave engineering and toward the qualities of experiences that students have that stay, or leave, and the kinds of engineers they become. Still, our study does suggest the general importance of *identification with and by engineering*, its double-sided character, and in ongoing work we are exploring whether these identifications vary in consequential ways by gender (Garrison, forthcoming). In this article, we have discussed another source of cultural variation that undoubtedly shapes students' experiences, that being the institutional context through which the student navigates (e.g., Urban Private University, Suburban Private University, Technical Public Institution, or Large Public University).

Casting about for a metaphor regarding the role of identification in becoming an engineer, we might name identification among our three dimensions as *the compass* that guides one to make a pathway through engineering. If that compass is lost or broken, students' commitment to meeting the challenges of rapid and unmarked shifts in what counts as engineering knowledge (ADK) and of navigating through a competitive, intense field amidst significant potential investment risks may too be lost.

If identification with engineering is as important as we are arguing, then certain recommendations can be made. Engineering programs can do more during the early years of an undergraduate engineering education to ensure that students have some strong identification with engineering. We will not prescribe what specific images we think might lead to increasing identification with engineering for all or most students (e.g., tinkering, good money, helping the world, being an innovator, or working in collaborative teams), because our research has taught us that people choose engineering for quite different reasons; as such, any of these might be good identifications to cultivate, depending on the particular student's interests and abilities. And in fact, some students legitimately choose engineering so that they can do something other than become professional engineers. Many choose engineering because it offers a promise of a comfortable material existence and in an earlier article we argued that this identification with engineering, as a lifestyle, counterbalanced a general sense among engineering students that they work too hard and sacrifice too much in comparison to other college students (Stevens et al., 2007). Although we do not want to pass judgment on this specific identification with engineering, we will say that engineering education might do a better job creating equally compelling identifications with images of engineering other than good money and a comfortable material lifestyle. Related to this, it seems to us vitally important for engineering programs to exert special efforts to identify and cultivate students who have nascent identifications that go beyond personal material gain. For example, Bryn, the Large Public University student discussed earlier who nearly left engineering because of its competitiveness and the premium placed on problem solving speed, would have departed not only with grades on par with many students who stayed in engineering, but also with her strong communication skills and her interest in integrating multiple perspectives in developing technologies intended for social good, qualities that fit quite well with recent calls to broaden the kinds of skills and interests engineers typically have and are increasingly sought after in professional engineering work. And while Bryn did technically remain in engineering, her degree was earned in an engineering discipline that frankly is seen as marginal by most engineers.

We have reported here on vast differences in students' ways of navigating their educational experiences and have exemplified, through our case studies of Simon and Jill, that these differences can be consequential. Jill took the official route as she understood it and she foundered; Simon, with the help of a trustworthy guide, took an unofficial route into engineering and by all current reckoning is moving toward a bright future as a practicing engineer. The concept of navigation as we are using it here bears a necessary conceptual relationship to how far and in what directions students have charted a course, which in turn depends on what, how far, and how clearly they see into the future. There is a good chance that Simon would not have charted a course through the testing facility had he not been confident that this was at least a viable alternative course to the official one through prescribed coursework. Ed Hutchins has used the term "horizons of observation" (Hutchins, 1995) to refer to the spatially located positions from which people can learn from others, and here we generalize this concept to longer timescales of learning and becoming. Clearly, Simon's horizons of observation were widened by his association with his friend, the engineering professor, as were the horizons of another student in our study, Anke, widened by a mentor at a government research lab where she worked as an intern before and during her engineering education (O'Connor et al., 2007; Stevens, O'Connor, and Garrison, 2005). Anke reported some less than ideal experiences in engineering education and reported a less than solid identification with engineering, an exception to our generally held view that identification is the primary compass that guides a student through engineering. Anke's compass was the prospect of a very specific future in this very particular research lab, doing scientific rather than engineering work. Getting through engineering was a means to that end, but an end that was visible only with horizons of observation opened up by interactions with a mentor at the research lab.

In general, the issue that these cases and others in our study raise is the importance of mentors or sponsors who do a particular sort of thing, provide images of futures and ways to get to those futures that are fully legitimate but do not appear in the official student guidebooks or in the recommendations of official advisors. Recommendations are hard to make here, because who counts as a mentor is not clear-cut, but qualitatively, Jill had different guidance than either Simon or Anke. While Jill had a family friend, an engineer, who suggested she consider engineering as a major, she never mentioned consulting with that friend again, and while she frequently met with her academic advisor in the department, the guidance she got there was largely about how to follow the official route.

We want to conclude by indicating how we think our three-dimensional conceptual framework should and should not be understood and used. In our view, it should be seen not primarily as offering a theory or model to be tested or validated, but rather as a set of interrelated "sensitizing concepts" (Blumer, 1969; Charmaz, 2007; Strauss and Corbin, 1990) that direct analytic attention toward aspects of learning and becoming that escape other perspectives. Yet, there are some theoretical hypotheses that might be pursued systematically in light of our dimensional framework. For example, one general hypothesis might be that a student's experience of *mismatches* among ADK, identification, and navigation is likely to bring about dilemmas that require further development and effort along at least one of the dimensions. Another hypothesis suggested by the dimensional framework is that the farther a student is from attaining institutional identification through official sources (e.g., in terms of ADK as indicated by a high GPA) the more unofficial navigational work will be required to attain this identification. Both of these hypotheses would likely be supported by our data in specific cases, but again the variability of student pathways reminds us to precede warily with regard to *a priori* predictions as to the general ways in which the dimensions and their interactions will be realized. In our view, we only have scratched the surface on the variability of pathways and more needs to be understood in this regard before seeking general covering principles of how people become engineers.

However, this is not to say that our sensitizing framework is unhelpful for informing research and policy. We firmly believe that it is and would suggest that a better approach than developing general models would be to use the framework to develop an understanding of specific dilemmas experienced by students and others in particular settings, such as specific universities or specific departments. To give just one example, we have reported above on a very common experience of ambivalent belonging and commitment among Large Public University students who are not admitted early to their majors, which leads in turn to various navigational and identity dilemmas. This represents a finding from our ethnographic work that had not been expected in advance. But now once understood and quickly regarded as "what everyone knows" (a common fate for ethnographic descriptions that move from invisible and unspoken to obvious), we have worked with administrators in the Large Public University's College of Engineering to make the implications of this structural dilemma clear and visible, and they have fed this knowledge into their own organizational process of considering significant changes that will likely lead the College to admit many more students earlier to engineering majors and thereby mitigate the very dilemma our research disclosed.

If such a change is made, the research findings will become part of the navigational field and hence contribute to new dilemmas or transform old ones. Engineering education is becoming like engineering itself—an informed tinkering culture, which is as it should be, and some of this tinkering is based on research like ours and some based on other varied inspirations that designers in all fields rely upon. As any programmatic changes are made to what is counted as engineering knowledge, in what identifications with engineering are cultivated, or how navigation is organized, new opportunities and new dilemmas will emerge for students. Our view is that these opportunities and dilemmas will likely be as unpredictable *a priori* as others we have described in this study, but will nonetheless be visible and knowable to person-centered ethnographic methods. Our strong recommendation, then, would be that both basic and applied research on engineering education must always routinely return to fieldwork of the kind reported here in order to continually "recover the person."

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