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ABSTRACT

Engineering is the application of scientific and engineering principles to site-specific, real-world problems. However, engineering education tends to focus on abstract, decontextualized, generalizable knowledge and learning tasks. Research was done to find out the results of adding out-of-class, real-world courses to the conventional engineering education program. The real-world courses provided opportunities for students to gather information from clients, and apply scientific, mathematical, and engineering principles to specific situations. The research followed three different design courses over four semesters. Participant observation field notes were collected and students and faculty were interviewed. The findings propose that an adequate theory of learning must include both micro- and macroscopic features of learning, relations of power, knowledge of real-world and academic practices, and ways to think about learning settings. Learning settings should be viewed as large systems with historical, social, and cultural entrenched ways of promoting one version of reality at the expense of others. Contains 4 tables, a figure, and 24 references. (BT)

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by Karen L. Tonso

Paper Presented at the 1998 Annual Meeting of American Educational Researchers Association
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INTRODUCTION

Recent research into learning in practice via participation in the everyday life of a community (Chaiklin & Lave, 1993; Eisenhart, Finkel, Behm, Lawrence, and Tonso, forthcoming; Holland & Eisenhart, 1990; Lave & Wenger, 1991; Levinson, Holland, & Foley, 1996) suggests ways to study academic preparation for professional careers. One such professional community of practice is engineering and one wonders about the extent to which engineering education prepares engineers for real-world work. Engineering practice focuses on the application of scientific and engineering principles to site-specific, real-world, practical problems. However, engineering education tends to focus on abstract, decontextualized, generalizable (propositional) knowledge and learning tasks preferred in the academic sciences. What happens when engineering curricular reform attempts to address this mismatch by adding courses expected to mimic real-world engineering practices? At the research site, engineering design courses were added to a conventional engineering curriculum. Thus, the research context was a hybrid learning setting that combined out-of-school, real-world practices with conventional ("academic" engineering) customs (Tonso, 1993, 1997a). Here, the pull of practical work met the push of academic achievement. How and what do students learn while completing real-world, practical engineering (design) projects for industry clients? How does the conventional engineering curriculum impinge on reform-minded engineering-design goals and practices? How does an engineering campus structure learning and knowledge and what does this tell us about the culturally-mediated co-constructions of learning, knowledge, and power?

SITUATED LEARNING FRAMEWORK

This research employed a synthesis of anthropological learning theories. Lave and Wenger's (1991) research into learning "out-of-school" in apprenticeships suggests that learning comes through participating in the everyday practices of a community and that becoming a mature practitioner guides or leads novice learners. Nespor's (1994) research in a college physics program suggests that learning has a more-global sense, that it extends in both space and time beyond the particular or local community of practice being studied. In particular, he writes that becoming a physicist or business manager means being "defined, enrolled and mobilized [via disciplinary practices and tools] along particular trajectories" that define networks of power, as well as "*producing and organizing* space and time" in disciplinary-appropriate ways (p. 9, emphasis his). Nespor is arguing that for physics and business management majors the post-secondary experience serves to launch certain kinds of persons into networks of power, and that the historical, social, and cultural education systems have the same sort of permanence that Lave and Wenger implied in their apprenticeships and categorized as communities of practice. As I interpret these theories, novices are learners becoming members of well-established communities with entrenched ways of "belonging" and it is in this process of fitting in and being recognized as fitting that "belonging" is produced.

I am, in this paper, primarily interested in the organization of engineering technical knowledge as it plays out in the engineering education community at PES. But in unpacking the organization of PES, I must extend the "novices as learners becoming mature practitioners" notions that Lave and Wenger and Nespor suggest. Allow me to summarize earlier writings about "cultural identity" (Tonso, 1997a, b). Both Lave and Wenger and Nespor treated mature-practitioner identities as taken-for-granted endpoints, such as tailor or physicist, but this left mature-practitioner identities under-theorized. As I use the term, "mature practitioner" implies a taken-for-granted *embodiment* of the past practices of a community, ways of behaving like community members that come via participation in the community's everyday practices, ways of demonstrating belonging - and being recognized as belonging - via employing community practices and tools (whether in an artisan's craft or an academic discipline). And, though left unspoken, "mature practitioner" suggests cultural identity, ways of fitting into historically-persistent systems of meanings and meaning-making processes.

This is a complex notion of identity that enlarges earlier discussions about identity in (primarily) psychological terms. In particular, *cultural identity* moves away from self-as-actor and encloses self in a cultural context that extends far beyond the here-and-now of immediate social context. Rather than focusing on identity as a manifestation of an individual's perception of him- or herself, I concentrate on a culturally-mediated identity and investigate the ways novices in the community tack back and forth between their sense of themselves and the culture's sense of novice participants as members. Through a culturally-mediated participatory process of student engineers seeing themselves as members of the engineering community (or not) and the engineering education community's recognizing student engineers as belonging (or not), mature practitioner cultural identities demonstrate "belonging" or membership via culturally-salient images. In these terms, cultural identity cannot be reduced solely to an individual's actions or beliefs about self, but because cultural identity encapsulates how a community of practice gives meaning to belonging, the varieties of belonging that are culturally entrenched and recognized. Thus, cultural-identity development is inextricably about participating as a member, being recognized by the community, and responding to cultural recognition. In this way, past practices, those deemed meaningful in the culture, are smuggled into (and taken for granted in) the here-and-now of social interactions among persons. Because of this, my research intends to pay considerable attention to "the way things have always been" and to note how these practices not only inscribe *belonging* for novices ostensibly joining a community of practice, but differentially distribute power to practitioners who reinforce customs and make them resistant to change.

"Engineer" seems to be the sort of cultural identity that falls at the intersection of Lave and Wenger's out-of-school apprenticeships and Nespor's disciplinary studies in the college years. Construing engineering as a community of practice implies both that becoming an engineer seems headed toward identities consonant with (and promoted by) the engineering profession, and that historically-developed ways of practicing engineering constitute shared meanings about belonging. In addition, an engineering cultural system of meaning encompasses not only academic training, but also technical language, tools of the engineering trade, social-interaction routines, and accepted practices for doing engineering work. Situated learning theory anticipates that as student engineers become engineers, they learn to be proficient practitioners in engineering systems of meaning; they learn to *enact* these systems of meaning. In other words, by taking engineering to be a cultural system, I imply that culturally-constructed engineering identities are a focal point of cultural learning, a way persons learn to *embody* past and current practices. Here, identity is worked on, made explicit, and manifested in a cultural context (Holland & Eisenhart, 1990; Kondo, 1990). This is not to imply that the culture dictates one's identity, but to recognize not only that there is considerable variety in the kinds of practitioners that "count" as engineers (while others go unnoticed, are made invisible, or are seen as not-engineers), but also that unexamined past engineering education practices shape the playing field upon which cultural identities are formed.

In addition to leaving mature-practitioner identity under-theorized, Lave and Wenger and Nespor seemed to accept in an unexamined way cultural identity development processes and outcome identities, and thus did not (or could not) undertake a critical analysis of links between cultural identity, learning, knowledge, gender, and power. In light of long-standing social inequities rooted in schooling (e.g., Eckert, 1989; Eisenhart, Finkel, Behm, Lawrence, & Tonso, forthcoming; Holland & Eisenhart, 1990; Willis, 1977), unexamined acceptance of past practices risks overlooking how communities of practice reproduce the status quo, which in engineering is profoundly gendered. I suspected that engineers came in several flavors and that different mature-practitioner (cultural) identities were associated with different kinds of learning and knowledge, some of which the campus culture supported at the expense of others. By following how cultural practices constructed and maintained links between and among identities, teamwork and classroom customs, and curricular structures, I document how power flowed on the campus, was culturally sustained, and played out in social interactions between (and among) student engineers. Taking this approach provided a way to connect the macro-structural, campus-wide organization of engineering education and the micro-social level of student-student interactions during teamwork.

In selecting sites for my research (Tonso, 1993, 1997a), I focused on locating on-campus learning settings that professed to value everyday, practical engineering work because these seemed the most-likely candidates for finding apprenticeship-like settings where situated learning theory was applicable. This meant that I would not be studying the vast majority of engineering classrooms, such as those where students learn calculus or physics or fluid mechanics (primarily) from texts via drill-and-practice problem sets, but instead would do fieldwork in engineering design classrooms. Design classes are a serious attempt to change the shape of engineering education and to accord status to the more-practical side of engineering. Design projects are considerably larger than textbook exercises, requiring teamwork for successful completion. Since teamwork is the industry norm, learning to work in teams is considered necessary training for all engineers. Design classes have the potential to incorporate complex real-world projects that are similar to those faced by practicing engineers, instead of the approach taken in conventional engineering courses that center on smaller bodies of knowledge, abstracted from the real world, with neat, clean, one-right-answer solutions. As innovative engineering courses expected to extend the "book-learning" of other courses, engineering design courses provide opportunities for teams of student engineers to complete real-world, often messy, projects that require not only gathering information from clients about their needs and interests, but also applying scientific, mathematical, and engineering principles to specific situations, as well as learning to communicate with industry employees ranging across the workplace from hourly laborers, to engineers, engineering managers, and non-technical managers.

Public Engineering School (PES), a state-supported college of engineering with programs typical of those at many engineering colleges, met these criteria. Undergraduate engineering enrollment was close to 2300 students, about 14% were ethnic minorities[1]. PES is coeducational and always has been. Women students comprised over 20% of the undergraduate enrollment, somewhat more than the national average of 18% (American Society for Engineering Education's 1995-1996 Survey). I chose PES because it stood out as an engineering college with more women

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[1] Though I intended to study issues of race and ethnicity, students from minority groups seemed too "recognizable" to secure their identities. Not only were there few student teams with more than one minority student, but also minority students seemed to come to the attention of faculty to a greater degree than their white colleagues.

students and professors than national averages, as well as because of its considerable collective will both to reform engineering education by adding design courses to the curriculum and to address concerns about women's education in engineering.

Table 1 summarizes the three different design courses followed over the course of four semesters of fieldwork (Tonso, 1993, 1997a).I collected participant-observation fieldnotes (in all class sessions and as I participated as an engineering colleague on student teams) and interviewed students on the teams twice and faculty in the classes once. I supplemented ethnographic data with a survey (of students' perceptions about the differences between conventional and design courses, n=274), with a curriculum analysis, and with a set of paired interviews (17 students) to elicit cultural identity terms and then to sort these terms into categories. Analysis proceeded in the interpretative tradition (Spradley, 1979, 1980; Van Maanen, 1988), documenting the diverse meanings that insiders constructed for explaining the engineering education system at my site.

Table 1. Makeup of Design Teams

Design Course	Teams	Women	Men	Total
First Year, one semester	3	7	5	12
Second Year, one semester	2	4	6	10
Fourth Year, two semesters	2	4	7	11
Total	7	15	18	33

In earlier papers (Tonso, 1997b, 1988), I detail PES cultural-identity categories and gender constructions and how those were learned and practiced. In this paper, I focus on how different conceptions of learning and knowledge held different status in the campus culture, how this played out in student-student interactions, and ultimately served to promote an "academic" engineering way of life that consolidated the power of some student engineers and reinforced the campus pecking order at the expense of students who practiced superior real-world engineering.

RESEARCH RESULTS

In this section, I summarize 1) the engineering-student cultural-identity categories elicited from student engineers and 2) the engineering design work of each senior team[2]. On the one hand, engineering-student cultural-identity categories encode the kinds of persons recognized as "belonging" at PES; while on the other hand, in-team participation provided access to the

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[2] I focus on the senior students because, in comparison to first- and second-year student engineers, only senior student engineers displayed the mature-practitioner cultural identities mapped in the cultural-identity categories.

culturally-mediated social interactions where students display, construct, and challenge "belonging" as engineers (to varying degrees) and where students *embody* engineering education's past (and current) practices through culturally-powered relations.

Engineering-Student Cultural-Identity Categories

Engineering-student cultural-identity categories revealed three arenas of belonging at PES: Greeks, Academic-Achievers, and Nerds (Fig. 1). Cultural-identity terms not explicitly gender-typed refer to men; that is, ostensibly ungendered terms, such as over-achiever, nerd, computer whiz, dork, geek, and so on, refer to men student engineers at PES. Key features of student life at PES are encoded in PES cultural-identity categories. First, there was a hierarchy of prestige that depended on being recognized for "academic" achievement via high grades, on-campus awards, service to the community, and other accolades. Second, the two higher-status categories (Greeks and Academic-Achievers, which students referred to collectively as Over-Achievers) were organized according to the extent to which students devoted their time to socializing or to studying. Finally, there were no female-typed cultural-identities in either the higher-status or lower-status categories most closely affiliated with engineering (Academic-Achievers and Nerds). Of the few female-marked terms, existing only among the Greeks, only one was a respectable identity (sorority woman) and the rest were (some) men's pejorative stereotypes of women (PES-woman, sorority chick, sorority girl, and betty).

Over-Achiever students met institutionally-defined criteria for excellence and were more visible in the social spaces where faculty and administration reside. Greeks used extensive institutionally-supported social networks to guarantee academic success in spite of time commitments to socializing which reduced time for engineering studies. Academic-Achievers did far less socializing than Greeks and had more time which they devoted to their academic work. Taken together, Greeks and Academic-Achievers comprised Over-Achievers, students who garnered financial and meritorious on-campus awards, had the most on-campus job interviews, went on the most plant trips (a job-site interview that is part of the courting rituals between industry and student engineers), received the most job offers, took the best jobs, and were courted by graduate schools. Those who "over-achieve" fulfilled academic institutions' definitions of success and were anointed with prestige and status in return. Yet, as will become apparent in subsequent sections, this recognition did not necessarily connote engineering capability.

In contrast to Over-Achievers, Nerds have sparser pedigrees and, on paper, appear less qualified than Academic-Achievers and have fewer social networks than Greeks. Nerds have little time or interest in either studying or socializing to the extent necessary to move out of Nerd-dom and into the high-status realm. In fact, many of the student engineers (with whom I worked) spoke with disdain about their Over-Achiever colleagues. Nerd-dom students were, by and large,

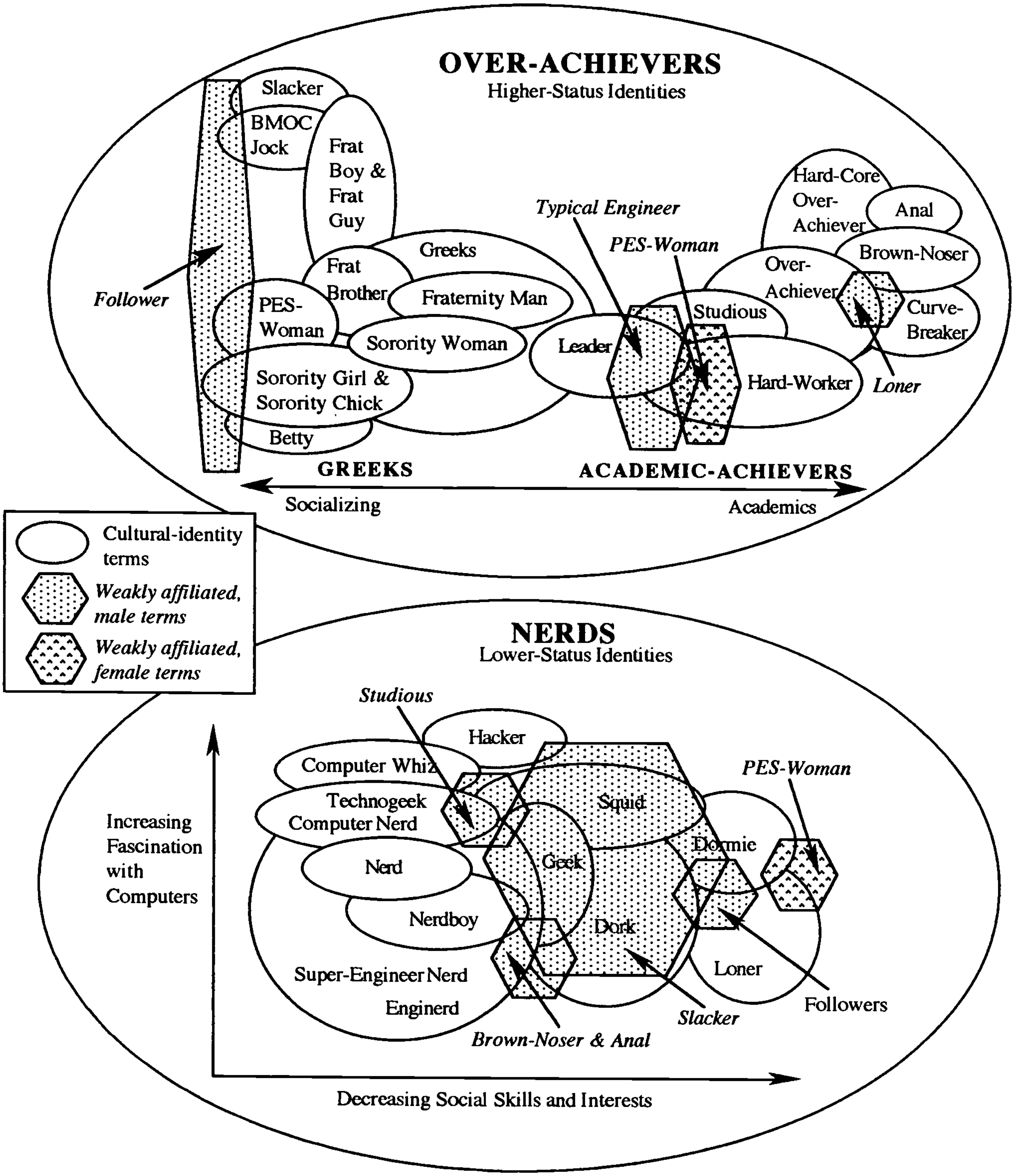

Figure 1. PES Engineering-Student Cultural-Identity Categories

academically successful, but not overly so. Most of them had extracurricular interests that spanned participating in service organizations and recreational sports (skiing, intramural sports, rock climbing, hiking, camping, motocross, mountain-biking, and roller-blading), as well as playing musical instruments and maintaining private pilots' licenses. Though men Nerds held power subordinate to men Over-Achievers, men Nerds still had a place in the PES system; they still "belonged."

However, as will become clearer in the discussion of senior-design teamwork, Nerds contributed substantially more to their teams' successes completing their clients' projects. Nerds plugged away, engaging in just enough socializing and entertainment to survive the academic rigors and "have a life," while Over-Achievers dodged their share of the work, avoided becoming involved, and developed arguments for both staying on the margins of the team's work and working in isolation from other team members which they thought was "more efficient."

Women's identities were singularly different from those of men. While men's cultural identities ranged across characteristics that accommodated those who worked hard to succeed and those who cut corners, those who valued interpersonal (social) skills and those who did not, those with high-level computer skills and those without; kinds of women were almost completely absent. At PES, female-marked identities among the Greeks occupied the lower-statused locations reserved for women, as ordered by dating rituals, even for the most respected term, sorority woman.

PES-woman ranged across the cultural-identity categories and was different from men's PES cultural-identity terms. Men's terms depended on observable actions and behaviors relative to engineering studies, but not to men's looks or sexuality. PES-woman encapsulated notions about women engineers as people who lacked physical attractiveness, as well as the disapproval of women who dated too much or were thought of as promiscuous. PES-woman linked good looks and sexuality to lack of academic success, as well as linking lack of attractiveness with academic success. This is hardly an acceptable "role" model. As a demeaning identity term with a long history at PES, PES-woman served to cast women into an "other" or "outsider" category singularly notable for indicating that women do not "belong." The PES cultural-identity terrain set the stage for social interactions and, over the course of engineering studies, produced gender discrimination.

That men would fit into the PES system *as engineers* was taken for granted, as was that women would not (Tonso, 1996). Taken together, the circumstances of women across the cultural-identity terrain relative to their men counterparts delimits the gender-status hierarchy at PES. Thus, for women Over-Achievers (who practiced "academic" engineering), their cultural identities - ways to embody engineering's past practices and engage the power enjoyed by Over-Achievers - were limited to the social (sorority-fraternity) realm where cultural identities carried with them the subordinate status of women in a normatively (white, middle-class) heterosexual society (Eckert, 1993; Holland & Eisenhart, 1990; Horowitz, 1987). Women Greeks were viewed as acting like women and not as "acting like engineers," in spite of their engineering-course academic-achievement credentials. Things were much worse for women who did not practice Greek-life socializing, but practiced kinds of engineering consistent with Nerd or Academic-Achiever ways of life. These non-Greek women were thoroughly erased from the cultural-identity terrain among the Nerds or Academic-Achievers. Thus, when women "acted like Nerd or Over-Achiever engineers," this did not count in the "belonging" system.

In the day-to-day social interactions of student engineers working to complete real-world projects for industry clients, we see how PES engineering education culture worked on student engineers, produced power, and reinforced a system that valued some kinds of engineers and engineering at the expense of others.

Student Teams in the Senior Design Class

At PES, most engineering departments required a two-semester *capstone* design class, opportunities for students to draw on their prior engineering course work, to synthesize and apply what they have learned to a real-world project, and to practice engineering in a setting where safety nets were still up. Senior-design teams worked as interns for industry and government clients solving a problem of interest to the client and, though challenging, within the scope of the capabilities of student engineers. Projects in the two-semester senior-design course I followed (open to students from all engineering specialties) were selected in such a way to promote teams of students from different engineering majors.

The fall semester was devoted to fact-finding and research as student teams negotiated their projects with clients. Throughout the year, students wrote one-page progress reports for their faculty advisors and gave formal and informal oral presentations during the once-a-week, whole-class meeting. Near the end of the fall semester, each team prepared a proposal that outlined the project and described what the team would accomplish during the spring semester, as well as estimated costs of needed materials, fabrication, and other items related to the team's work. In the spring semester, ironing out unforeseen difficulties while implementing proposed technical plans provided the crucible for minute-to-minute refinement of on-paper designs. At the end of the spring semester, each team prepared a final report for the client documenting the team's solution to the client's project. Student teams also gave formal oral presentations to their clients at the end of both semesters.

Students met for 50 minutes each week in a whole-class setting. Teams spent the vast majority of their time outside of class, where they met for a minimum of three hours every week to discuss and work on their project, as well as meeting for 30 minutes each week with their faculty advisor to report their progress and seek advice. Individual students also worked on their own to make calculations, procure materials, and chase down resources or industry contacts, which they discussed at team meetings. Based on students' comments and my observations, I estimated that most students averaged at least nine hours a week on senior design, roughly the same amount they reported for other three-hour classes.

In the next two sections, I summarize the everyday life of two very different senior design teams. The Mercury Team set out to create a mathematical model of a proprietary technology for removing mercury from power-plant flue-gas emissions. However, some students on this team shirked their part of the work, volunteered for high-visibility public performances, and exploited their hard-working colleagues. In the final analysis, these "slackers" came from high-status locations in the identity terrain and were the most likely to do little or no "actual" engineering. However, other students on the team practiced magnificent "actual" engineering, the melding of scientific and engineering principles with real-world, site-specific, technical and non-technical constraints. Pam became the heart and soul of her team's engineering, while Sam supported her efforts without challenging his higher-status colleagues. Pam was invisible in the public spaces where professors and company-engineers observed the team's engineering products, and suffered both exploitation of her work by some of her non-contributing teammates (Carol, Shane, and especially Pete) and academic hazing from Carson, otherwise a capable colleague.

The Sludge Team designed a personal-computer-based, data-acquisition system to monitor pump pressure on a sludge-disposal system and reduce maintenance costs. Their teamwork practices exhibited respect for one another, shared decision making, and a closer link with their design project than was the case on the Mercury Team. However, Jessica and Russell, students with high-status identities, did less work, though not to the extent of the "slackers" on the Mercury Team. In ways that regularly impressed me, students on the Sludge Team practiced engineering of professional caliber; in fact, comparable to what I came to expect during my 15 years practicing engineering. Marianne, Martin, and Nate were the premier engineering practitioners on this team. Though in many ways very similar to Pam on the Mercury Team, Marianne's teamwork experiences were vastly different from Pam's.

Watch as student engineers demonstrate their affiliations with campus cultural-identity categories, especially the extent to which they promote different goals that are consistent with "belonging" in different niches in the culture. Also, notice who can press a particular vantage point on their engineering work and make it stick. Three powerful men deserve extra scrutiny. On the one hand, Pete and Carson on the Mercury Team illustrate abusive uses of cultural power. On the other hand, Martin on the Sludge Team demonstrates constructive uses of cultural power.

Mercury Team

Six students comprised the Mercury Team (Table 2). All six students came to college immediately after high school. Though they came from towns varying in size from large to small, urban to rural, all had been in a competitive academic track in high school and entered PES with high grade-point averages and college entrance exam scores. Three of the students had high college grade-point averages, a fact known to their colleagues. Also, the students knew that Pete was on a prestigious "full-ride" academic scholarship. All six students expected to participate in the May graduation ceremony, though three (Pam, Pete, and Shane) would complete their coursework during summer school.

Table 2: Students on the Mercury Team

Name	Engineering Specialty	Years to Graduate	College GPA*
Pam	Chemical Engineering	5 + summer school	Moderate
Carol	Electrical Engineering	4	Moderate-High
Carson	Mechanical Engineering	5	High
Pete	Chemical Engineering	4 + summer school	High
Shane	Chemical Engineering	4 + summer school	High
Samuel	Chemical Engineering	4	Moderate-High

* High ≥ 3.8, Moderate-High 3.3-3.8, Moderate 2.9-3.3

The Mercury Team worked for A-Tech, a small company that specialized in developing environmental technology for industrial users. The project the company proposed centered around a proprietary process for removing trace amounts of mercury from the flue-gas emissions of coal-fired power plants. In a nutshell, the process for removing mercury from flue gas depended on passing flue gas through a porous media impregnated with elemental gold, amalgamating the mercury with the gold, switching the amalgamation bed off-line (diverting mercury-laden flue gas to another bed), and using heat to drive off the amalgamated mercury which was carried by a purge gas to a condenser for collection of elemental mercury. The "scrubbed" flue gas then went up the power-plant stacks and into the atmosphere. The company's proprietary process represented an improvement on an existing technology, if economic and technical feasibility could be demonstrated. The technological challenge of this process resulted from the gigantic volumes of flue gas (one million cubic feet per minute) and the minuscule amounts of mercury present (estimated at 600 pounds per year), a concentration of about 10 micrograms of mercury per cubic meter of flue gas. This kind of technology is used, on a much smaller scale, in catalytic converters on passenger cars. Thinking of the power plant in these terms means that the Mercury Team is designing a catalytic converter that will be about the size of a high school gymnasium.

When the students entered the discussion, the company understood the process "in theory" and was in the process of developing a proposal for a small-scale field test. Because of mercury's toxicity, especially mercury in the vapor phase, the student team's project would have limited hands-on aspects. This left the students to research how amalgamation and desorption "worked," to design a vessel that could be packed with sorbant and alternately heated and cooled, to select a condenser and mercury meter, and to develop an economic simulator of the process that allowed changing key variables and investigating the sensitivity of the process to changes in variables.

The team divided their responsibilities along lines they thought matched different phases of the engineering work:

Pam	mass transfer - determine the quantity of catalyst and the amount of gold on the catalyst needed to adsorb the mercury from the flue-gas stream
Carson	heat transfer - determine a catalytic converter shape that can be heated to drive off the mercury and cooled to return it to the amalgamation phase
Samuel	mathematical simulator - create a spreadsheet that links process specifications to economic variables, run a set of cases to determine how sensitive the economics are to changes in the process variables and specifications
Shane	sorbant materials and economics - locate sorbants, acquire samples and physical properties of samples, plus compare the cost of the A-Tech process to the older activated-carbon technology
Pete	condenser selection - use the concentration of mercury in the purge gas and purge gas flow rates to select a condenser suited to the application
Carol	mercury sensor - determine the kinds of sensors available to measure small amounts of mercury in the gas leaving the amalgamation-bed and either recommend a sensor for the application or explain why no sensor currently exists

This division of work persisted during the two-semester design course. As the team's design work unfolded, this division of labor set the stage for inequitable work distributions.

The Mercury Team's two-hour, Thursday morning meetings were the site of specific scientific and engineering (technical) work and power dynamics. They performed all "teamwork" in this context and, when major reports or oral presentations were due, the team time was spent on those tasks and engineering calculations came to a halt. It is important that readers pay close attention to the experiences Pam had. She was the heart and soul of her team's engineering work. Yet, by performing high-quality, practical engineering work, Pam did not reap the expected benefits of demonstrating engineering expertise. Rather than making her a person who could be trusted as an engineer, performing engineering work brought the intense scrutiny of Carson, as well as exploitation by Pete and Shane. This did not happen to Carol who contributed considerably less to the team's work.

Listen to excerpts of team meetings[3]. At their February 15 meeting, Pam, Carson, and

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[3] Throughout this paper, vignettes and student dialogues (presented in smaller font) are adapted from Tonso (1997a).

Samuel applied scientific and engineering principles to the project, while Carol, Pete, and Shane performed very little "actual" engineering. In addition, Carson focused his efforts on checking Pam's work, while he failed to meet his teamwork commitments. Inaction was contributing to a crisis, because the team had not noticed that their preliminary design would not meet the A-Tech-specified small pressure differential across the catalyst.

While Pam churns out engineering computations, Carson and Samuel seem to be waiting for her results. At the other end of the table, Shane provides a running commentary as he thumbs through the equipment catalogues. Pete and Carol chuckle and nod at Shane's comments. As has become the custom at team meetings, when Pam nears the end of her calculations, Carson asks her to explain to him what she found.

Carson: Well, are we going to be able to extrapolate the trend in the sorbant efficiency with time?

Pam: That's exactly what I'm inferring. (Pam answers him curtly.)

Carson: Well, where's the total amount of sorbant per day?

Pam: Why? (She's beginning to bristle.)

Carson: Well, so how much?

Pam: So 20 cubic meters lasts for 22 days. So divide them and you'll get it.

Samuel: So I get 253 kilograms of sorbant per day. The sorbant has one weight percent gold.

Carson: Well, I'm using different assumptions. So how much mercury is sorbed?

Pam: Well, the client and three professors told me to do it this way. What's the problem? (She's becoming more irritated with Carson.)

Carson: I'm not doing heat transfer. I'm doing how much we need. (Since Carson is supposed to be focusing on the heat transfer properties of the regeneration cycle, this is tantamount to his saying he won't do any work until she gets done with her part and he can pass judgment that she's done it correctly.)

Pam: Why? That's what I'm doing.

Carson: So we can check each other. What assumptions did you use?

Pam: None.

Carson: Well, I'll work through this and figure out what's going on and then we'll talk.

Pam continued to puzzle her way through calculating the surface area that the flue gas must flow through. She tries to determine the pore volume of a honeycomb sorbant, the amount of space where the flue gas will flow - small hexagonal tubes. Pam, with the help of Pete and Samuel, ultimately determined how much of the volume of the sorbant is tubes and what portion is ceramic and used that to compute the interstitial pore volume:

Pam: How much volume in a cell, so that if it's 100 cells per square inch, each cell is a hundredth of an inch

---

Because it was in the ebb and flow of teamwork discourse that contestations about what counted as engineering or who belonged in engineering took place, I include teamwork dialogue and not snippets of discourse. To do otherwise would misrepresent student teamwork. In the excerpts, ellipses (...) indicate my skipping a portion of the discussion, parentheses indicate clarifying remarks or observations, and square brackets indicate additions that I made to the dialogue or my interpretations of the actions.

squared, a hundredth of an inch squared on a side, it's a tenth of an inch on the side?

Carson: Yes, so you can call the wall thickness a hundredth of an inch, one one-hundredth of an inch.

Pete: You can calculate that, 70% is cells, 30% is not.

Carson: So 47.6 cubic meters of blocks to get 20 cubic meters of solid....

Pam: So, 20 cubic meters of, well, why is that?

Carson: I gave you the number of 0.326 cubic meters per day of sorbant, 1 weight percent of gold for the alumina. So you take the gold, you need 100 times as much, so the alumina weight percent and that's without porosity. So 0.326 meters cubed per day, with 0% porosity, so

Samuel: So that density takes into account porosity?

Pam: I don't know. Why isn't anybody else doing calculations? We only have one month to finish this up and I'm the only one doing calculations here.

This is a fairly accurate appraisal of the realities. Carol, Shane, and Pete sit idly at the other end of the table and, though Samuel and Carson follow along with Pam's calculations, they are not really doing calculations of their own. Amazingly, her rather loud and angry accusation goes unacknowledged. Her teammates did not flinch, shrug, nod, look away, or otherwise appear to notice. Carson speaks as if Pam's accusation never happened:

Carson: (To Samuel,) did you get it done yet? Did your 0.326 alumina, did it include the porosity or not?

Samuel: Yeah. [I think he means that it did include the porosity.]

Carson: So 0.326 cubic meters takes into account this number (the interstitial porosity)?

Pam: I don't know. I'm doing it the way the professor said. I'm trying to work it up from first principles without assumptions. (She answers Carson curtly and seems to be angered that he continues to scrutinize her work, but does not make progress on the heat transfer calculations. She is in fact trying to take the interstitial porosity into account, but seems to lack the technical vocabulary for talking about it.)

Shane: Are we going to break for lunch?

Pete: Whatever.

Samuel: I need to go now, but we've got a half an hour before we have to get back together [for the regularly scheduled class time].

Within a few minutes, the team dispersed. Since they attended class during the lunch hour and went immediately to lab sessions after that, students rushed to grab a bite to eat, since eating in the library and classrooms was not permitted. Throughout the team meeting, Pam diligently worked through several ways of thinking about their dilemma. She used Samuel as her foil. He and Pam usually sat with their heads together and hashed out enormous amounts of chemical engineering knowledge. It is sometimes difficult to gauge Samuel's contributions from these transcripts because he was very soft-spoken, especially after being maligned by Carson early in the Fall semester for not seeming prepared prior to presenting the team's progress to the entire class (though he gave an outstanding oral presentation) and after having Pete always comment to their faculty advisor that Sam was habitually late, when in fact Samuel was on time and Pete was early.

As the flow rate and pressure drop dilemma became more evident, the possibility of considerable last-minute revising sent teammates into a variety of activities. While Pam, Carson, and Sam took the bull by the horns and calculated their way out, Pete stayed on the margins and never quite understood the dilemma, but took credit for the team's work when their faculty advisor was present. Listen as Pete uses his powerful position to call the shots and to produce himself as a knight in shining armor:

At the team's meeting on February 29, Carson realized the seriousness of their problem:

> Carson: So you want to buy extra sorbant to save money on a fan? A million cubic feet per minute, the flow rate of the flue gas, through 2/3's of a meter of [pore volume in the] bed, that is one helluva pressure drop. We have got a big bottleneck.

Later during the same meeting, Pete finally understands the import of Pam's and Carson's concerns by depending on them for technical information:

> Pete: What's the speed of the flue gas?
>
> Carson: Well, a million cubic feet, per minute,
>
> Pete: What's the bed velocity?
>
> Carson: Wind tunnel.
>
> Pete: Well, we have 10 tubes, the gas is going to go through there at 1,146 miles per hour....So, we want it to be big per the reactor?
>
> Carson: Well, per bed, it's 6.05 cubic meters. Do we have converged assumptions? [Are we using the same set of assumptions?] (Carson restates the assumptions for Pete.)
>
> Pete: I believe you. Ten of the tubes, 6 inch diameter, so 27 feet high...(as he punches numbers into his calculator).
>
> Carson: The velocity?
>
> Pete: 1,400 miles per hour. Mach 2.8. [Mach 1 is the speed of sound, about 1100 feet per second. 1,400 mph is roughly Mach 1.9, not 2.8. I think he's blowing smoke, engineering talk for creating the illusion of expertise.]
>
> Carson: Let me run that.
>
> Pete: Well, if we go 100 of these, and it's only 2.7 feet high, then it's only 140 miles per hour. The beads are going to become a fluidized bed. They'll be shaking and rattling. (Carson confirms Pete's calculations.)

On March 7, Pete exaggerated the dilemma, as if this were not something that engineers could resolve:

> Pete: What about flow velocities through the bed? Did you come up with a way to get the gas to slow down? We can't expect the retention time to be OK if the bed is small. So with that cross-sectional area, stuff's going to be moving 140 miles per hour, through the beds. We need some residence time. I think we need about a tenth of a second. Well, if we had one bed, it'd be a bigger bed.

In his second question, notice how Pete continues to see this as someone else's problem, not his. Rather than asking "How could <u>we</u> get the gas to slow down?," Pete asks "Did <u>you</u> come up with a way to slow the gas down?"

> Carson: Well, we started with three ten-day beds.
>
> Pete: What if we had three 22-day beds? It'd take, maybe it takes 8 hours to regenerate? A 60-day bed would take 24 hours?

As far as I can tell, Pete is pulling these numbers out of thin air. Because Carson has not done the heat transfer computations, the time required for regeneration - to heat the bed to 700 degrees Fahrenheit, purge it with an inert gas, and return it to adsorption - is still unknown.

Carson: ...How long the bed is determines the sorption [adsorption time] and how long it's going to take. If it's moving 140 miles per hour, you have to have a longer bed, and the longer bed would have to be skinnier [to keep the same volume].

Pam: So, Dr. Lucas was talking about ways of slowing it down.

Pete: How?

Pam: Well, by expanding [the size], so you split the bed to combine [the flow across several beds] and maintain the pressure drop. [This suggestion means that the team must change their assumed bed configuration, though to what is not clear.]...

Pete: The problem is [we're] at the beginning of March and we're working with more than one bed all semester. I don't think we should switch now. We'd only make the switch if we had to by necessity. So we don't want to change it just to improve something, but because three beds wouldn't work. If we see that there's going to be a problem, we can go to two beds. So let's not change at this late date. We need to go through the whole thing again. Does anybody agree? What do you think about this?

Pete takes his usual stance of advocating the least work possible, of deferring work as long as possible, and of gathering support for his position. The team has become enamored of their preliminary case and forgotten that the size and shape of the bed were based on estimates made without taking the pressure drop into consideration.

Pam: I think it's way too much to do that now [change from their three-bed case].

Carson: Well, my concern is you say that there's a big change at this point. We're going to get down the road and not be able to do it that way [meet the pressure differential criterion with our preliminary estimate of three beds].

Pete: I've been trying to do those calculations on flow velocities and I need to keep researching it. If by necessity we have to slow, then we'll have to slow it down.

The necessity was clear on February 29, a week before this exchange. That Pete has been trying to do these calculations is news to me and I strongly suspect that Pete overstates his effort. Other than the back-of-the-envelope calculations Pete and Carson generated on February 29, there is no evidence that he has done any calculations. Based on his past practices, his use of the word "researching" is synonymous with "avoid doing anything." This calculation is a relatively basic one that does not require researching, but doing.

Pam: So we'll look at the calculation way back when. For 85,000 hours [roughly 10 years], the sorbant can handle it [high flow rates and rattling around].

Pete: What?

Pam: The flow rate.

Pete: At 1,000 miles per hour?!! We're not talking changing pressure; we're talking blowing stuff out. We're going to get a tornado. You know, a straw through a brick wall. If it's fast enough, we're going to fluidize the particles and we don't want them rubbing against each other.

He's over-reacting and using hyperbole to create precisely the re-configuration crisis that Carson advocated above, though none of the other students seemed to appreciate Pete's shifting positions. In fact, there are advantages to having a turbulent flow regime through the bed, as Pam reminds Pete.

Pam: We have to have turbulence, because it's [the mercury-concentration profile in the bed needs to be] flat. Because of the beads, that mixing across the bed, you want to get an even distribution of mercury and Dr. Lucas said that we need to be in a turbulent flow regime [to accomplish that].

Students and I continue to work on resolving the dilemma of meeting both constraints, flow rate and pressure drop. Carson and I have been doing more calculations:

Karen: (To Carson,) 20 cubic meters, where did that come from? Is that 10 or 20 days on-line?

Pam: 22 days.

Carson: So if we want a residence time of a tenth of a second, we've got to have a bed volume of 120 cubic meters.

Karen: So 132 days on line? How long is the bed at 40 miles an hour?

Carson: 5.86 feet.

Karen: How many 10-inch-diameter tubes in 710 square feet?

Carson: Oh, Jesus! That's 1300 tubes. Oh shit! Oh, oh, oh! (Needless-to-say, 1300 10-inch-diameter tubes are not a reasonable solution for the power-plant situation.)...

Pete: (Returns to the meeting after running errands to prepare for the in-class oral that he and Shane will present.) So they [A-Tech] did their experiments [in their bench-top model] with the velocity around 0.5 to 1 feet per second? (I think that Carson agrees with him.)...

Shane: (Arrives at 11:35.) Well, if you're worried about a fluidized bed, what about using the honeycomb? (An alternative porous media upon which to disperse elemental gold.)

Carson: Well, the client was worried about knocking the gold off the sides. [I don't remember it that way. I thought that knocking the gold off the sorbant would be a problem common to the three different ceramic materials.] Karen and I assumed 40 miles per hour and calculated a cross-sectional area.

But before Carson could finish summarizing our calculations for Pete, Dr. Stanley arrived at 11:36. What happened next illustrates the extent to which Pete exploited his teammates. Based on three team meetings (February 15, 29, and March 7), Pete contributed very little to resolving the dilemma of meeting the pressure drop criterion in light of the high flow rate. In fact, based on what he said so far, there is little evidence that Pete understood the problem in enough detail to describe it to another engineer, much less to resolve it. But this does not stand in his way when he takes credit for "discovering this problem." We rejoin the team-meeting dialogue as Dr. Stanley enters:

Dr. Stanley: Hi, everyone.

Pete: You're late, buddy.

Dr. Stanley: How's it going?

Pam: Not too swift.

Pete: Well, I'm going to take all the credit for discovering this problem. So they [A-Tech] did their experiment at a flow rate that's real slow. We've got a million cubic feet per minute to get down. So we're trying to figure out how to get that down, to anything, to get the velocity down. So we have to have a large surface area. So 100, 10-inch tubes is 200 miles an hour. That's going to blow the beads out. And if it fluidizes the bed, it's going to rub them [the beads] together and that's not going to be OK.

In addition to his snatching the credit, there are inaccuracies in his explanation. In particular, 200 miles per hour is a fictitious velocity. Our conversations had revolved around 140 miles per hour. In fact, just moments before, Carson was in the middle of explaining how he and I were backing into a surface area calculation assuming a velocity of 40 miles per hour. Furthermore, Pete continued to ignore Pam's discussion with Dr. Lucas, one of her professors, which led Pete to assume that a fluidized bed was a bad thing, though Dr. Lucas suggested that the team needed a fluidized bed.

Without the kind of detailed knowledge that came through participating in the teamwork, Dr. Stanley had no way to gauge the accuracy of Pete's claim. Understanding what professors see and value proved critical to appreciating the extent to which the campus-wide organization recognized kinds of engineers and kinds of engineering work. I will return to this after discussing both teams, but first discuss the Mercury Team students' locations in the cultural-identity terrain.

Students on the Mercury Team thought of each other in cultural-identity terms, which we discussed during end-of-semester interviews. Both Carson and Pete were considered hard-core over-achievers, Academic-Achievers who depended almost solely on their grade-point averages for status and regularly benefited at the expense of others. Carson eventually completed the heat-transfer calculations and developed a shell-and-tube vessel configuration that met the process criteria. Pete, on the other hand, rarely contributed beyond the public oral and written performances for faculty, client, and/or other teams. At the final presentation to the client, when Pete should have been an expert on condensers, he could not give even the most rudimentary description of this central piece of equipment. Pete's behavior was well known on campus among students and faculty. In fact, one of the senior design professors remarked, "He's viciously not collaborative. This person would stab his mother if it would help him keep his [high grade-point average]" (Field notes, 8-24-95, p. 1). Another professor didn't think it was quite that bad, but agreed that it was going to be a problem. Though their teammates groused about their behaviors during interviews and other private conversations with me, no one ever challenged Carson or Pete when I was present. Both Pete and Carson were aggressively pursued by on-campus employment recruiters, made several job trips, had several offers, and accepted lucrative jobs. Both expected to graduate at or near the top of their class.

Shane and Carol took a lackadaisical attitude toward the design work and contributed only small amounts of engineering work. Both also managed to perform more in the public spaces than in the teamwork settings. However, they were not as aggressively exploitative or as controlling as Carson and Pete. In their design work, Carol and Shane kept to themselves, took on little work, and barely met almost non-existent commitments to the team. Other students thought of Shane as an over-achiever and his high grades and avoidance of design work supported that identity. As a likable fellow, his teammates never seemed to mind that he did so little. Carol's grades were fairly high and she seemed to fit best into that area of the Academic-Achiever map where studious and hard-worker identities intersected, though no one ever referred to her in these terms. Both interviewed on campus for jobs, took a few job trips, and accepted jobs that they desired.

Samuel and Pam carried the team, performing the vast majority of the team's engineering work. Neither received the kinds of rewards that this should have garnered. Both performed fewer public performances, especially for faculty. Both placed very high value on understanding how the entire process hung together. Samuel was considered a nerd, just one of the guys who plugged away and cranked out enough engineering to survive the under-graduate program. He had only a few on-campus job interviews and almost no interview trips. He accepted a job with a small chemical processing plant. No one ever referred to Pam using any cultural-identity terms. Had she been a man, I feel certain that she would have been considered a Nerd (super-engineer nerd or nerdboy). By not noticing Pam's contributions to the teamwork (such as the discussion about fluidized beds, which Pete never appreciated), her Over-Achiever teammates contributed to making Pam invisible. Pam had almost no on-campus interviews, virtually no interview trips, and no job offers. When she graduated, she was unemployed and only later found short-term work with A-Tech, the team's client.

On the Mercury Team, performing design work was a liability for students with high-prestige cultural identities. As hard-core over-achievers, Pete and Carson went to great lengths to maintain stratospheric GPSa by controlling written and oral public performances and exploiting the work of their teammates. Other high-prestige student engineers (Carol and Shane), located where grades were important but exploiting one's teammates was unacceptable, went with the flow and performed very little design engineering. Lower-status engineers (Pam and Samuel) performed most of the engineering, but received little credit for it. In particular, the higher-status student engineers were well known for their achievement in conventional engineering classes where decontextualized "academic" knowledge held sway, while lower-status student engineers actively mined the scientific and engineering principles applicable to their project and made sense of the world in thoroughly novel ways. Thus, by seeing the world through the cultural framework that privileged "academic" over "actual" engineering, by using their power to promote their academic way of life, and by avoiding doing any "actual" engineering themselves, Over-Achievers (to varying degrees) reinforced the PES cultural system.

On the Mercury Team, "academic" engineering was championed by powerful student engineers and performing more-practical engineering meant running counter to the no-work practices of Over-Achievers, as well as ultimately being exploited by precisely those student engineers who argued against doing any work. This did not happen to the same extent on the Sludge Team where different cultural-power circumstances existed.

Sludge Team

Five students comprised the team (Table 3). Though the students came from a variety of towns ranging from large to small, urban to rural, all participated in a competitive academic track in high school. They arrived at college immediately after high school with high grade-point averages and college entrance exam scores. All five students expected to participate in the May graduation ceremony, though Russell would complete his coursework over the summer.

As the Sludge Team's project emerged during the fall semester, the team elected to provide

Table 3: Students on the Sludge Team

Name	Engineering Specialty	Years to Graduate	College GPA*
Jessica	Electrical Engineering	4	Moderate-High
Marianne	Mechanical Engineering	5	Moderate
Martin	Electrical Engineering & Computer Science	5	Moderate-High
Nate	Mechanical Engineering	4	High
Russell	Mechanical Engineering	4+summer school	High

* High ≥ 3.8, Moderate-High 3.3-3.8, Moderate 2.9-3.3

a PC-based data-acquisition system to monitor a portion of Private Power's sludge-disposal facility. The power plant was located adjacent to their largest customer, a manufacturing plant. As with many large industrial plants, waste from manufacturing processes and shop floors was collected and disposed of according to government regulations. Many plants bury the waste at considerable expense, but this manufacturing company incinerated it in the power-plant boilers, also at considerable expense. Through a complicated system of piping, pumps, and nozzles, the "sludge" from the manufacturer's waste treatment plant was incinerated in power-plant boilers. The design team arrived about the same time as power-plant managers became aware of rapidly increasing sludge-disposal-system maintenance costs. By monitoring the back-pressure on the outlet side of the sludge pumps, the Sludge Team planned to gather information to better understand the pumping system, information the company would use to reduce maintenance costs.

This team met regularly in two different contexts. The first was their regularly-scheduled meeting for two to three hours at the power plant in a small conference room. Curtis, their client contact and an engineering manager, usually met with them for at least 30 minutes (and often longer) after which the students continued their discussions as needed. Curtis treated the students like engineering colleagues, recognizing that he knew more about the plant operations, but that students would know more about other things through their engineering training. The second regular meeting place was Martin's apartment about two miles from campus. Though this team recognized that meetings with everyone present tended to be somewhat less "efficient" than meeting in two's or three's, their commitment to involve everyone in the teamwork - both work done at the power plant and its reporting to the faculty via oral and written reports - required that everyone be present. Since these ad hoc meetings to create faculty-required products did not usurp the team's regular meeting time, technical work did not come to a halt while students attended to the more student-like coursework requirements.

The students did not have fixed task responsibilities, but tended to share the load among themselves based on each student's expertise, balancing the time and energy expended within the shifting constraints of their other coursework and social obligations. Because there was considerable overlap in their expertise, responsibilities flowed among the students with one person taking the lead on a particular facet one week and another the next. For instance, though Martin was the acknowledged computer-programming expert, he and Nate shared those tasks. This team demonstrated high-level engineering work and respectful interpersonal working relations, as well as minute-to-minute shared decision-making.

In the following excerpts from their team meeting on October 31, notice that everyone must understand the situation before the team can move on. Pay particular attention to the very different kind of treatment that Marianne experiences compared to what we saw happening to Pam. Notice that, even when an avowed expert makes a suggestion, students discuss the suggestion and develop an understanding of the expert's reason for it, as well as add to the store of information from their own expertise. Observe that Jessica and Russell focus on grades more than on technical work. Notice the extent to which their client contact, Curtis, depends on the students for information that he does not have, and simultaneously provides detailed information about the power plant where he has worked for over 10 years.

> Martin: (Pulls a catalog out of his backpack.) Here's the bottom-of-the-line data-acquisition boards. The low cost one is $695 and there is one [that is] just I/O [input/output] board for 395 [dollars].
>
> Jessica: Do you think, will they meet our needs?
>
> Martin: Well, they might. But if you're going to spend $700, you might as well get a top of the line model for 1800 [dollars].
>
> Russell: Maybe we could go with the midrange.
>
> Martin: Yeah, we'll probably end up without enough money and have to make our own. Here's one that's just 200 bucks, but it's just a digital I/O board. The $700 [one] is a multi-function I/O [board].
>
> Marianne: Are we going to have to get an A-to-D board [an electronic device that converts analog measurements to digital readouts]?
>
> Jessica: Did Nate not know that we're going to meet at 9:30 [which is 30 minutes earlier than they have been meeting]?
>
> Russell: He's on a plant trip with [a national company, interviewing for a job]....Well, I probably shouldn't tell you this, but Nate told me he'd be happy to do whatever needs to be done. (Others agree; they've been told that as well.)
>
> Martin: (Still looking at the catalog,) well, I think these are working at a pretty low level. I suspect we're going to have to do more processing [and will need a more sophisticated data-acquisition board].

Martin's way of investigating DAQ-boards illustrates his commitment to shared decision-making. Rather than making a decision outside the team and then arriving at the meeting to push for a specific DAQ-board, Martin brought the catalog to the team meeting, browsed through it, talked about the application, and deferred the DAQ-board selection until they had more information. Only Marianne seemed to understand the engineering considerations well enough to be Martin's foil. The discussion then shifted to the team's first draft of their project proposal:

> Russell: Were they happy with our report? Have you heard from anybody, that they were happy with our

report?

Martin: (Kidding Russell) Well, they were unhappy you didn't sign it.

Russell: You have my authority to fake it at any time.

Martin: I was proud of the report. I thought it came together pretty well.

Jessica: I probably shouldn't say this, but rumor has it that Dr. Norton is reasonable about that sort of stuff, the timing and the grading; that she's pretty easy going.

Russell: That's good to know....How do they grade it anyway? (No one seems to know and they ask me what I know. I tell them, I've never heard anything said about the way in which the grading works, nor how they use all the different observations of the students, like oral presentations and written reports, to arrive at a grade.)

Jessica: Well, I heard that they get together at the end of the year, go to breakfast, and they discuss each student in turn. [Her description matched what I had seen done the previous year.]

This team spent relatively little time discussing issues related to grades or what the professors expected, but Russell and Jessica usually instigated these infrequent discussions. Martin's response that he "was proud of the report" was typical of the way he used his personal standards, and not those of the faculty, to judge the team's efforts.

The client entered and started by saying that he told his boss that the team would focus on the sludge system.

Curtis: I've been scrambling to piece together some material for you. I wrote a paper in 1990, from an advanced class in mechanical engineering I took. I want to make a copy of this for all of you. The paper goes over the design of the system. I'm hoping there's a drawing here. This is it. (He has two file folders that are crammed full of papers and he's shuffling through these and finding a report. Then, looking through this single report,) this is the description of the system. The verbiage may not match the diagrams very well, but with a physical look at the system, this will be a good starting point. Oh, and I've included some baghouse information here. We can't just put anything in the combustion stream of the boilers. Ours are coal fired; so any time we want to put anything into the combustion stream, we're concerned about the integrity of the fabric filter system. So here's the paper in its entirety. This I'll copy....

Curtis is making apparent the ways in which the sludge-disposal system is integrated into both the manufacturing plant and the power plant operations.

Martin: Is that [waste-treatment plant] across the highway?

Curtis: Yes. (And he leaves to make the copies of the paper.)...

Russell: Does the school have a board [for I/O, input/output] that we can use right now?

Martin: It's not an option right now. We want to convince [Private Power] to invest in our project. There is that digital I/O stuff in the control lab though.

Russell: Oh, I remember those. Those things from the field session, I forget what they were.

This last exchange between Russell and Martin exemplifies the different things they each learned in the same classes. Martin knows where different kinds of equipment, especially electrical equipment, reside on campus and can judge the likelihood of students' borrowing them for design projects. His recollections about these matters were about applying these technologies to the design project. Russell, on the other hand, rarely understands his prior coursework in this way. Everyone on the team knew that Russell had the highest GPA, leading me to wonder what he learned there.

Curtis returned about 20 minutes later and filled us in on the particulars of the two waste-treatment plants the manufacturing company operates. The flow of information about the sludge-disposal system and the team's ideas for monitoring it became the topic of the conversation. This information-sharing is a two-way street between Curtis and the students. While Curtis is learning about data-acquisition systems and the team's plans for using one, the team is learning about the sludge-disposal system.

Curtis: They pay us to handle the material. So if we reduce the cost of handling the material, it'll be a benefit to Private Power. Your focus on gathering data and information will allow you to make recommendations on a different style of pump. Your first step will be to develop, through instruments and applications in the system, an energy balance of the operation. Focus on the elements of the operation and you can either improve pump design, reduce electricity demand, [or] operate more efficiently. What do you think?

Martin: We can do that.

Curtis: Well, I don't want to put words in your mouth.

Marianne: So, we're talking about an energy balance on the sludge system from the minute it hits here.

Curtis: Yes; we refer [by using the term "energy balance"] to what we use in handling the system; for instance, electricity, steam, and then maintenance.

Martin: Well, we could either put in sensors to monitor, or if that's too costly,

Curtis: Oh, no. We can easily afford that. We can support you[r] getting field devices. Help us think about how to centralize and the analytical instrumentation.

Martin: What I'm imagining now is a permanent, low-cost installation on the pumps.

Curtis: Well, it may not be permanent.

Martin: Well, anyway, we could look at the displays [in the control room] versus the flow rate you're getting and the BTUs you're getting. You could see the energy balance. You can look at the system and see where it's going. Maybe you'll say, "It costs us 33 cents a day to operate this thing."

Curtis: Yes, you develop a monitoring system part of it. (He leaves at 10:21.)

Martin: So, we're thinking right now it's not going to be an accelerometer [a sophisticated application to measure vibrations and related to preventive maintenance, a research interest of the professor that Marianne works for in a campus research lab]. But we could propose that as an added feature, so that you have a pop-up window and you could see how it's operating in the frequency domain. You could set up alarms and all kinds of things. But for now, I think we should focus on flow meters.

Marianne: Yeah, it'd be nice if we could do what they want.

At this point, the team has a sense of the range of possibilities for their project, but lacks a sense of the physical operations. Before Curtis went to his weekly staff meeting, he returned and took us to see the sludge system. Martin and Marianne scrambled around the sludge-disposal system and located pumps, valves, and electronic monitoring and reporting devices, which they linked by following electrical conduits. Jessica and Russell stood and looked at the system, but did not seem to understand it.

Russell comes over and asks me a question about the equipment. We step into the stairwell and close the door to talk in the relative quiet away from the plant noise. His question centers around the kinds of information currently monitored on the sludge system and where the meters and gauges are located. We return to the plant floor where I point out features of the system. First, I show him how the pressure is monitored by large dial gauges just downstream of the pumps. These gauges are read manually and, since no electrical leads come from these, the pressure information is not currently sent to the operators in the control room or kept systematically. Second, I indicate how in-line flow meters are installed on the outlet side of each pump, with read-outs on the adjacent wall. I suspect that these flow rates are sent to the control room and displayed for the operators. We locate the electrical wiring from each flow meter that sends this information to a monitoring system. We walk over to the control system (a self-contained box about twice the size of a large home refrigerator) where Martin remarks that the monitoring system also works as a controller, but is out-dated. He thinks a PC-based data-acquisition system would be a big improvement. Electrical leads coming out of controller box go back to the pump motor drivers, indicating pump operations can be manipulated from the control room upstairs. Martin thinks that we should be able to pick up the flow-rate signal and input it to our proposed system.

We complete our visit of the sludge system by visiting the control room upstairs. While there, we sort out which parts of the control panel relate to the sludge-disposal system and practice "reading" the information displayed there with dials, lights, switches, and digital number displays. The operator on duty answers our questions, but defers to Curtis to explain some things.

Learning about the plant was an integral part of the design process and many different kinds of non-text resources (operators, equipment configurations, interpretation of the control panel) held important knowledge about the sludge-disposal system. The Sludge Team's project gave them opportunities to see how engineers fit into the larger, corporate scheme of things, experiences their conventional classes did not provide.

Meetings at Martin's apartment were usually motivated by upcoming faculty-required oral or written reports and occurred outside of the team's scheduled out-of-class meeting. These meetings were characterized by good will, everyone tackling a different piece of the report, and nobody getting too "freaked out" by the fact that work was not proceeding like clockwork. The Sludge Team enjoyed being together. When they gathered at Martin's, they converged on Martin's bedroom, dropped their packs on the floor, pulled up chairs, sat on the bed or floor, and engaged in continuous conversation about the project, their other classes, and their social lives. Martin created a team-meeting climate that was conducive to working together and exuded care for other people. Though it is usually women who are noted for creating the "atmosphere" for social settings, Martin exhibited considerable skill doing this. This made meetings at his apartment a welcome respite from the wear-and-tear of the students' college lives and from my own field-work fatigue. Maybe it was being raised in a region of the U.S. where hospitality is an art form, but he understood and practiced a care for other people that took into account who was visiting and what their interests were. It was important to him that people felt welcome and he put substantial effort into facilitating this climate, though he made it appear effortless.

At a meeting to preview a software package using Martin's VCR, he again demonstrated his skill including everyone in the team's engineering conversations. Listen as the team discussed configuring the software to perform the system monitoring tasks desired (February 19). Recall that Martin is the acknowledged computer expert. Notice Marianne's treatment, especially how her need to keep the meeting short is met.

> Martin: I think we need a chart and a button, where we can do high resolution versus more broad measurements. Then [for] the chart, I think you want to have a play and a pause. We want to stop and look at the shape of the chart, we want to be able to save the data and dump it to a file, and we want to be able to tell it not to acquire data.

The students discussed his proposal and modified it slightly to account for other eventualities. Marianne articulated a sense of the link between the software and the pumping system:

Marianne: We need to get a basic feel for the pumps, [because] we want to compare it [the pump's performance under operating conditions] to the manufacturer's specifications. We want to set a high point and see how many times it goes over that. We want to have a counter, probably, so we'll see how high it'll spike on the pressure and see the relationship [between pressure and pump health].

As the discussion proceeded, Martin continued to explain his ideas as he answered his colleagues' questions. Throughout this conversation, he continuously updated his sketches. At one point, he explained his sketch to Jessica:

Martin: This is the way I see it.

Jessica: You have four blocks?

Martin: Yeah, we see that [on the computer screen], like we can see the EKG of each patient [or in the case of the sludge pumps, the pressure profile on each of the four pumps].

While the other students digressed and talked about an upcoming on-campus social event, Martin hurriedly re-sketched his interface. We continued to look at features of the interface and to discuss things that other students need to accomplish, such as working with Curtis to decide where in the pumping system the pressure transducers will be installed. Russell asked for an estimate of the programming time and Martin replied that it depended on the input and output to files.

Marianne wants to leave, ostensibly to go do other homework. Earlier, she mentioned that her fiancé's car broke down and that she must loan him her car for a few days. After the meeting, she expects to drive 15-20 miles across town, pick him up, and have him bring her back to her apartment. This means that she will not get to her other homework until an hour or more after we adjourn and expects a long night. Her off-campus social relations with her fiancé and family were a part of several commitments that she routinely juggled and balanced with her on-campus duties. When the meeting got off track, she made her needs known by saying she needs to "go do other homework." But Martin wants to show her his program panels. He promises that they are almost done and she will be able to leave soon. This exchange was typical of the way that the Sludge Team provided a forum where Marianne's commitments could be considered in the team's work. This was not something that ever occurred for Pam in the Mercury Team.

Returning to the team meeting, Martin then describes the system as it currently stands:

Martin: Here's what's going to happen. The first phase we'll put the board in. That'll be all groovy and we'll have a "display" and a "frequency" knob. You'll set the sampling parameters and it has "play" and "pause" buttons. You'll be able to acquire data and stop acquiring data. You'll have indicators and show a running average or recent max, with a reset....

It's going to have buttons and an icon - a clock [will be the icon for] the time-logger. We need an icon for the event [logger]....My best one for an icon is a camera. That's going to be our snapshot logger. We can hit it and record a chunk. That's in the recent memory and we can also pause and log it. Each icon is going to have ways to set it up....We want a "start-and-stop" logging button.

We want to be able to set up a file, give it a name, say whether you want all the pumps, or just a specific pump...or an event trigger, to record that one. I want to write a header every time the file's created. We need to put in some write-to clicks....We need a sample length to take the average, a sample period. We need a max amount of time. If it's left running, it'll time itself out, because we can't get too much data for the computer to hold it....I'm going to have a box for the filename, and radio buttons so you can include all of the pumps or just a special one, and you want an event logger threshold, and a maximum frequency. Maybe we don't need that. I want a two-way toggle on the threshold, original rise in pressure, and option of the toggle time to record data. In the next three minutes, record until the slope goes negative, or levels off. We want to be able to see the whole picture that we have at a time.

When his team mates confirm that this sounds fine to them, Martin says, "I feel happier. I think I know what we need to be doing."

> Though he is the recognized programming expert on the team, he requires the input of the team before he can proceed with software development. Martin is not just going through the motions of teamwork, but requiring that the team understand his vision and provide substantive commentary before he and Nate begin programming. With this plan in hand, Nate and Martin have enough guidance to complete the task and, three weeks later, they loaded the program on Private Power's computer. While Martin and Nate developed the software, Marianne, Jessica, and Russell kept the hardware installation moving forward.

Through these interactions, student engineers on the Sludge Team demonstrated their locations across the PES cultural-identity terrain and with it differing commitments to engineering work. Martin, Nate, and Marianne were beginning to understand themselves in terms of their contributions to the plant - Martin and Nate's contribution coming through developing the software interface, and Marianne's from selecting the pressure transducers. Russell and Jessica were not as engaged with these hands-on, real-world aspects of the project and tended to be more interested in *how* the team was doing than in *what* the team was doing. By framing their engineering work in these terms, students performed cultural-identities.

Russell was considered a fraternity man, Jessica a sorority woman, both in the Greek cultural-identity category. They gave considerably more time to their fraternity and sorority commitments than to their design work. For example, on March 21, Russell had to leave the team's regularly scheduled meeting to attend another meeting. Russell's meetings had become a logistical hurdle for the team. When Russell announced that he was leaving, Nate and Martin spoke simultaneously saying "You and your meetings" (Field notes, 3-21, p. 4). Martin went on to comment that Russell "should attend MA, Meetings Anonymous." In a similar fashion, Jessica placed her sorority meetings and intramural volleyball games ahead of evening design team meetings. Neither demonstrated robust engineering knowledge. Russell had little idea what to do with the knowledge he acquired in conventional classes and Jessica bumbled an elementary calculation (for an electrical engineer), making her engineering knowledge suspect. Jessica had a high GPA, while Russell had both a near-perfect GPA and a "full-ride" scholarship (the same award Pete enjoyed). However, neither Jessica nor Russell practiced the kinds of exploitation that Pete and Carson demonstrated, but seemed more like Shane and Carol. Both Jessica and Russell spent the summer between their junior and senior years as interns, an indication of on-campus recognition. Jessica had many on-campus job interviews, plant trips, and job offers. She accepted a lucrative job offer. Through an oversight, Russell found himself three hours short of enough credits to complete his degree. He planned to spend the summer working as an intern with a major chemical processing company and taking an economics course by correspondence, and then to look for full-time employment in the Fall when he had his diploma in hand.

Nate was considered a studious, hard-working engineering student, where Greek and Academic-Achiever cultural-identity categories overlap. He did not get ahead by exploiting others and worked hard on the team's design project. He consistently demonstrated respect for his colleagues and his interactions with them were the sort one anticipated from a person with a profoundly ethical sense of participation and collaboration. His interactions with Jessica and Marianne exhibited a deep-seated respect for them as engineers. At one point, he surprised Marianne by complimenting her skills. In her surprise at being complimented, something that had never happened to her at PES, she accused him of being sarcastic. He replied, "Oh, no!...[Y]ou're really good at this." During an interview, he expressed shock and dismay that he was the only student engineer who ever acknowledged her engineering ability. He had many on-campus interviews, went on several job trips, and accepted a job that, though lower-paying, was well-matched to his desire to perform ethical engineering for worthwhile social causes.

Martin and Marianne were considered outstanding engineers who could work their way through the complex mazes of real-world practice. Martin was considered a computer whiz (in the Nerd category), indicating not only his well-above-average computer skills, but also a willingness to take the time, always a commodity in short supply, to help other people out of a computing jam. He also demonstrated extraordinary engineering management skills that were seldom displayed outside the team. Marianne's real-world engineering experiences and skill exceeded her teammates'. She was recognized by her teammates as the person who kept the team connected both to their campus commitments, to those at Private Power, and to their out-of-school social lives. Though her lower GPA lobbied against her being considered an Academic-Achiever, Marianne otherwise met the criteria for a studious, hard-working cultural identity. Had she been a man, she would probably have been considered among the Nerds because of her ability to make the links between academic and real-world engineering. Martin had some on-campus interviews, a few plant trips, and a couple of job offers. He accepted a job with a local software development company, worked there part-time until the end of the semester and full time after graduation. Though Marianne had some on-campus interviews, I was not aware that she took any plant trips. In spite of her considerable engineering prowess, Marianne did not have an industry job when she graduated. Fortunately, she was well connected in her department and the department chair found funding to employ her as a teaching assistant in the summer lab courses.

Martin's and Marianne's leadership on the Sludge Team promoted "actual" engineering, the complex kinds of activities common to everyday, practical engineering: applying engineering principles; taking into account other non-technical factors, such as economics, environmental concerns, the interests of the general public, and the in-house preferences of industry clients; behaving ethically by not exploiting engineering colleagues, misrepresenting the engineering work done, or endangering others in society who may not understand the import of engineering decisions. And, Jessica's and Russell's low-key participation did not alter the teamwork approach, though both benefited somewhat from their colleagues' hard work.

As with the Mercury Team, most of the Sludge Team's engineering was outside the purview of faculty. This meant that the exemplary engineering practices of the Sludge Team passed unnoticed in the PES engineering education culture. Let us turn now to illuminating how faculty monitored engineering design work and, in the bargain, promoted "academic" engineering.

Faculty Shortchange Engineering Work via Assessment Practices

By organizing the senior design class in such a way to structure faculty out of student teamwork, "making the grade" became disjoint from "doing" engineering. At PES only a limited amount of engineering work came under the purview of faculty (Table 4). In particular, the faculty stayed out of the way of student teamwork and monitored the progress of individual student engineers and of student teams via conventional written products and oral presentations. Thus, in this environment, engineering work - so far as the educational system was concerned - existed only in out-of-team public performances for the class, faculty, and/or clients and in written products mandated by the course syllabus.

Oral reports occurred in three venues. The first came when student teams met with their

Table 4: Faculty Glimpses of Student Work

		Type of Product		Responsibility	
Week	Assessment Item - "Deliverable"	Written	Oral	Indiv'l	Team
4	Letter of intent to client to faculty & client	x			x
5	Timeline to faculty	x			x
6	10-minute oral to entire class		x	x	
7	Written progress reports	x		x	
9	Proposal draft to faculty	x			x
10	Proposal draft to client	x			x
11	Written progress reports to faculty	x		x	
12	Proposal draft #2 to faculty	x			x
14	Final proposal to faculty & client	x			x
15	Oral to client & faculty		x		x
	& written progress reports to faculty	x		x	
17	Revised timeline to faculty &	x			x
	oral report on process to entire class		x	x	
19	Narrative outline of final report to faculty	x			x
20	Oral to entire class		x	x	
	& written progress reports to faculty	x		x	
23&24	Oral to entire class		x	x	
	& written progress reports to faculty	x		x	
27	Report draft to faculty	x			x
30	Oral to faculty and client & written report to faculty & client	x	x		x

advisor on a weekly basis. As demonstrated by the Mercury Team's not reporting their dilemmas to Dr. Stanley and by the ease with which Pete usurped the credit for others' work, these weekly meetings provided opportunities for students to represent and misrepresent their team's progress. Without better ideas of what was going on in team meetings, faculty could not tell the difference.

The second occurred in regularly scheduled presentations in class to faculty and student classmates. Since each student engineer had to give at least one in-class oral, students took turns giving them. Faculty's in-class comments about these oral presentations focused almost exclusively on superficial aspects of public speaking, such as not going over the time limit, standing next to the screen instead of by the overhead projector, and checking for spelling errors on the overhead slides. Only egregious engineering errors or misstatements received comments. There was no way to judge whether what was being said was factual or adequately represented the team's progress.

The third came in major oral presentations to industry clients. Students with closer affiliations to the academic way of life tended to make their presence known by taking on large portions of these presentations. For instance, Shane, who sat on the teamwork sidelines for most of the year, always prepared the overhead slides since he had access to sophisticated software and could organize a PC-based slide show. Pam who had done well over half of the engineering work on the Mercury Team never participated in orals to the client. Though every student on the Sludge Team gave a portion of oral presentations to the client, Russell and Jessica presented information that clearly came from Martin and Marianne's expertise. Again, it was not clear that faculty could discern whether the presentations were factual or not, but company engineers (and I) had a better appreciation of the realities. For instance, at the Mercury Team's final oral, one of the company engineers asked Pete to say more about the condenser. His answer was a model of ignorance:

> It's just a simple [condenser]. I'm finding with several companies, when [I contacted them], it doesn't have to be lined with Inconel [mercury-corrosion-resistant nickel-alloy] since the temperature we were optimally looking at is just 100 degrees Fahrenheit. So you don't have to worry about some of the properties of the mercury like at 700 degrees Fahrenheit. Just from the information I received, it's just a standard [condenser]. (Field notes, 4-25. p. 13)

A company engineer shared my suspicions about Pete's lack of expertise and probed further about the condenser: "Shell and tube? Water running through it?" In other words, is this the simplest kind of condenser imaginable? In our post-oral debriefing with Dr. Stanley, he never mentioned that he noticed Pete's ignorance, in spite of the fact that he had taken Carol to task just the week before when her section of the final report seemed thin, something that Pam and Samuel corrected.

Written products included progress reports, drafts of reports, and final reports. At regular intervals, each student engineer wrote a progress report that the faculty advisor glanced over and placed in a file. Student teammates never saw what their colleagues professed to be doing on the team, nor did faculty advisors check that these progress reports were factual. Being able to blithely misrepresent one's contributions could not be differentiated from performing engineering.

In addition, teams' wrote two large reports, one at the end of the first semester and the other at the end of the second semester. These reports went through at least two drafts and faculty provided ungraded feedback to the team before the client saw the report. As with the individual student progress reports, faculty had no basis on which to evaluate the extent to which the report represented what the team had been doing, nor could faculty verify the efforts of students on each team and judge teamwork practices.

Through this way of assessing and evaluating only very conventional academic tasks, faculty failed to recognize the engineering that student teams were doing. This kept the unsavory practices of the Mercury Team, as well as the magnificent engineering of Pam and Samuel, hidden from view in the PES engineering education system. Likewise, the exemplary practices of the Sludge Team - both engineering work and teamwork, as well as Jessica's and Russell's diminished work effort and engineering quality - were hidden from view. The PES engineering education culture reinforced past academic practices and failed to intervene in inferior teams or to recognize superior ones.

DISCUSSION OF RESULTS

Learning at Public Engineering School (PES) was characterized by difference. What students do, aspire to, and want varied by and within settings. Students on the same team, ostensibly engaged in the *same* activity, learned different things. Students in different locations of PES engineering education's hierarchy were motivated in different ways. Student engineers, even those on the same team, were engaged in different practices. Students' locations in the PES hierarchy, especially engaging and enacting a *cultural* identity, delimited meaning-making on design teams. And, only some of the student engineers (with less-prestigious identities) were learning and demonstrating "actual" engineering. In spite of the design projects' potential to provide splendid opportunities for practicing engineering, those people actually learning to do "actual" engineering were not recognized by faculty or campus-wide award and job-hiring practices, did not earn status, and ultimately were not taken seriously for what they did. Because women were not considered "real" engineers in the PES system, women who demonstrated magnificent engineering skills never belonged.

Comparing the engineering work of students on PES engineering design teams with Hutchens' (1993) example of sailors on navigation teams highlights the complex cultural and social "navigations" that student engineers were learning to perform. Hutchens' sailors filled well-defined niches in a rule-bound social organization. The vast majority of knowledge about navigation was built into the equipment, and other "tools," of navigation. Sailors learned how to use existing equipment, then employed that set of skills and those tools to navigate. Thus, in their practice of navigation, sailors followed an algorithm, a kind of "practice" more akin to procedural "recipes" than to problem-solving of the sort practiced in design teams. The powered relations between and among the sailors on navigation teams were set by a rigid chain of command. Sailors, by and large, made no changes to the algorithm or their navigation tools on-the-fly, as part of their "practice." Furthermore, so long as the ship docked without hitting anything in the process, navigation was successful.

Work done by engineering design teams differs markedly from navigation. Engineering design projects are not routinized applications of previously-acquired knowledge or skills, something that Hutchens' sailors took for granted. Each design project required that student teams create relevant kinds of equipment or processes, or put together off-the-shelf items in novel ways to meet a specific goal. No one - not students, professors, or clients - knew what to do to complete the project successfully at the outset, nor in fact just what the project might be. As teamwork progressed, it became clear that component tasks were very much up for grabs, or in the case of students with the highest prestige, something to be dodged. Different students held different conceptions about their team's focus and about how best to perform component tasks of projects. Though almost everything about their design work was open to debate and could be contested, students received no preparation for resolving differences of opinion in ways that promoted high-quality engineering processes and products. This left teamwork open to abusive, as well as constructive, uses of power. Finally, what counted as success was implicitly determined by the conventional curriculum and influenced students' approaches to practical engineering and team work, while the success system never explicitly included design work or teamwork.

Under these circumstances, success in their design work came to mean different things to different students and teams at PES. For some students, success meant getting good grades through any means necessary, including exploiting their teammates, cheating, and hood-winking professors. Others took success to mean doing no more than writing technical reports that fit faculty's expectations, without regard either for teamwork or for practical engineering. And, some students (and teams) thought of success as treating colleagues with respect, performing engineering work that could be depended on, and meeting faculty's technical-writing and oral-presentation requirements. Rather than teams taking a perspective on their engineering work of the sort Holland and Reeves (1994) documented, perspectives on engineering work at PES fell into two cultural grooves where different learning environments and knowledge systems prevailed.

Like their high-status "academic" engineering colleagues, students who practiced "actual" engineering had learned a tremendous amount in their conventional classes. Design teams were outstanding learning environments, places where students attempted to make academic learning relevant and did. Few learning environments in formal schooling compare. Student engineers who practiced "actual" engineering learned something important about the practice of engineering. In particular, design projects promoted linking academic knowledge with real-world situations, sharing responsibilities and trusting colleagues, communicating engineering knowledge to technical and non-technical members of business communities, and filling gaps in students' knowledge. As an engineer with extensive industry experience, I knew almost immediately that learning "actual" engineering in design teams was "the real McCoy." Students practicing "actual" engineering found design projects enormously successful, instructive, and rewarding. These were robust learning environments that meet the call of educational researchers for people who can *really* solve problems; and are precisely the kind of experiences that industry purports to value in engineers. (See Dutson, Todd, Magleby, & Sorenson, 1997, for a review.)

Even though PES design teams meet and exceed the criteria for making learning relevant by incorporating practical work, as championed by many educational researchers (e.g., Chaiklin & Lave, 1993; Eisenhart, et al., forthcoming; Hutchens, 1993; Levinson, Foley, & Holland, 1996; Nespor, 1994), one very irritating fact remained. No one among the PES powers-that-be was paying attention to this program that works for so many students. By distorting engineering practice through an "academic" lens that paid too much attention to written products and oral presentations, a kind of student work that can be handed in or delivered directly to professors and graded in conventional academic ways, PES failed to take seriously what "actual" engineering is or might be and to reward those students who practice "actual" engineering. In this way, PES promoted students who practice "academic" engineering at the expense of other students and, in the bargain, produced culturally-powerful student engineers who, via social interactions with less-powerful student engineers, reinforced the PES status quo.

This paper expands discussions of sociocultural theories of learning, such as distributed cognition (Brown, Ash, Rutherford, Nakagawa, Gordon, & Campione, 1993), assisted performance (Tharp & Gallimore, 1988), assisted apprenticeship (Rogoff, 1990), situated learning in communities of practice (Lave & Wenger, 1991), and networks of power (Nespor, 1994). At PES, what was learned and how it was learned proved more "relational" than "distributed," "assisted," or "situated." Learning was relational in two ways: first, as related to students' locations among the cultural-identity categories, and second, as produced in culturally-powered student relations during teamwork interactions. To "belong," as an engineer, a tailor, a physicist, or a business manager, is fundamentally about fitting into an entrenched system which may not recognize every practitioner to the same extent, in spite of the similarity of the actions of individual participants. To overlook the extent to which the system constrains, defines, produces, reproduces, and creates "belonging" and to place too much emphasis on individual action may lead to over-estimating the degree to which individuals control becoming mature practitioners and risks mischaracterizing the choices offered to participants.

Learning as related to "belonging" in a community of practice and as relating to others in the community is not captured by sociocultural learning theories centered in psychological perspectives. Rogoff (1990) and Tharp and Gallimore (1988) envision that learning occurs when children engage in social interactions with other students with a teacher present who "assists" each students' cognitive development. They use "apprenticeship" as a metaphor for the interaction between a teacher (as the master) and students (as apprentices). Brown, et al. (1993) take a similar approach by considering students to be "...apprentice learners, learning how to think and reason in a wide variety of domains" (p. 190). Using apprenticeship as metaphor fails to recognize that classroom teacher is not the sort of robust cultural identity required to underpin a cultural system and overlooks the possibility that some other categorization of cultural identity may be leading.

There is something fundamentally different going on in communities of practice, such as Lave and Wenger's real-world apprenticeships, Nespor's physics and management disciplines, and my engineering campus. What makes something a community of practice is the permanence with which it precedes its participants, outlasts them, and reaches to spatially and temporally "other" sites in the community of practice. Clearly, this is what Nespor had in mind when he referred to networks of power, as did Lave and Wenger by using apprenticeships. However, neither situated learning theory or networks of power can account for the differential power that belonging confers on some mature practitioners relative to others, or on those practitioners being produced as not belonging. Overlooking the extent to which power played out in the production of "belonging" at PES seriously misrepresents how the campus culture organized learning and knowledge. "Belonging," as fashioned on the PES campus, emerged via the construction of "academic" engineering as superior to "actual" engineering, and played out in culturally-powered relations between and among student engineers. When gender status was layered on top of academic prestige (Tonso, 1998), women "academic" engineers were either confined to their "womanly" subordinated place in a normatively heterosexual world of Greek life (Eckert, 1993; Holland & Eisenhart, 1990) or made invisible as Academic-Achievers, and women "actual" engineers were thoroughly cheated out of belonging.

From my findings, I propose that an adequate theory of learning must account for 1) both micro- and macroscopic features of learning, connecting individual learners to system-wide practices, 2) relations of power, 3) knowledge of real-world <u>and</u> academic practices, and 4) ways to think about learning settings as large systems with historically-, socially-, and culturally-entrenched ways of promoting one version of reality at the expense of others. Developing research strategies for seeing both the temporally immediate and the histori-culturally tenacious features of learning environments provides promise for understanding which of these cultural systems are worth replicating in our schools. I, for one, would not relish having the PES culture taken as an appropriate model for public schooling. Though it has been beyond the scope of my work to date, my PES findings suggest that some kinds of high school (college preparatory) math and science programs should be under far more scrutiny than they seem to get and that reform in these high school programs may be a far more difficult task than imagined.

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