AC 2008-1891: INTEGRATING TECHNICAL, SOCIAL, AND AESTHETIC ANALYSIS IN THE PRODUCT DESIGN STUDIO: A CASE STUDY AND MODEL FOR A NEW LIBERAL EDUCATION FOR ENGINEERS

Dean Nieusma, Rensselaer Polytechnic Institute

Dean Nieusma's research and teaching focus on interdisciplinary design collaboration and the expertise that enables it. With a BS in mechanical engineering and another in general studies and a PhD in interdisciplinary social sciences, Dean has worked as a member of design teams in contexts as diverse as the U.S. and European automotive industries; Sri Lanka's renewable energy sector; and STS, engineering, and design curriculum planning. He teaches across Rensselaer's Product Design and Innovation studio sequence, including courses in industrial design, entrepreneurship and design, and sustainability design.

Integrating Technical, Social, and Aesthetic Analysis in the Product Design Studio: A Case Study and Model for a New Liberal Education for Engineers

Abstract

This paper investigates one initiative to bring technical, social, and aesthetic analyses together in the same curriculum and even in the same classroom. Rensselaer's Product Design and Innovation (PDI) program was initiated in 1999 in an effort to integrate engineering, STS, and arts/architecture pedagogy within a single program. PDI students typically receive a dual-degree (usually in STS and engineering), and the curriculum is built upon a foundation of interdisciplinary design studios, where technical, social, and aesthetic concerns are dealt with simultaneously by faculty representing disciplines in engineering, STS, and arts/architecture. The paper reviews the PDI curricular structure as well as pedagogical experimentation surrounding PDI studios, highlighting the role of theoretical contributions from STS and how these are integrated into product design pedagogy. While the PDI program has been remarkably successful in attracting students, no systematic study has been done of the underlying approach of the program's pedagogy or the effectiveness of integrating STS and aesthetics insights into the students' design process. Based on interviews with faculty and students and a review of compiled student feedback, this paper provides a first-round description of the program's underlying approach and evaluates the program's success in creating a new, liberal engineering design education. It also assesses institutional challenges and how they impact the PDI program's character and effectiveness. Ultimately, the paper shows how the design studio can be structured to be an ideal setting for genuinely liberal engineering education, because, under the right conditions, it allows integration of diverse disciplinary approaches in a way that is both pedagogically coherent and immediately relevant to students' experiences.

Introduction

> [S]ystemic engineering reform, and its [traditional] curricular and programmatic forms…, will only have limited success until the relationship between engineers' identity and knowledge and method is fully addressed, and an integration of the liberal arts—particularly those areas dealing with the relationship between engineering and culture and politics—takes place.[1]

This paper analyzes Rensselaer's Product Design and Innovation (PDI) program as a potential model for a new liberal education for engineering students that achieves the high level of integration of technical and liberal arts approaches. The PDI program entails a set of interdisciplinary, undergraduate courses and degree options that span engineering, the humanities and social sciences (H&SS), design disciplines, and management. Initiated in the mid-1990s, PDI was motivated primarily by the desires 1) to combine the strengths of various disciplinary approaches to social problem solving and 2) to revamp undergraduate engineering curricula by including systematic analysis of the social context of engineering problems. By being integrative, interdisciplinary, and systematically attentive to the social context of engineering work, PDI addresses fundamental shortcomings in the H&SS-electives model of traditional engineering curricula, where liberal arts content is "elected" by students idiosyncratically and is separated cognitively, spatially, and temporally from their core engineering coursework. By bringing liberal arts and technical content together in way that is both comprehensible to students and administratively feasible, PDI provides a compelling model for a new approach to liberal arts education in engineering. Like many innovative curricular initiatives, however, PDI is made possible by an institutionally unique configuration of forces and players, making difficult the possibility of replication. By describing the program's major characteristics, and by extracting the main pedagogical approaches employed by instructors in the program, this paper seeks to convey enough detail of PDI to enable adaptation to or hybridization within other institutional settings.

While many facets of PDI could be considered relevant to understanding the initiative as a new approach to liberal arts education for engineering students, this paper will focus on two aspects of the program—curricular structure and key theoretical frameworks that underlie classroom pedagogy. Before discussing the PDI program, however, the paper briefly reviews approaches to design and liberal arts pedagogy and Langdon Winner's provocative argument for a new field of inquiry, which he dubs "political ergonomics." The paper then introduces Rensselaer's PDI program and discusses two components of PDI's curricular structure: the design studio sequence and what will be called the program's "radical interdisciplinary." After reviewing PDI's structure, the paper turns to classroom pedagogy, emphasizing theoretical approaches derived from science and technology studies, or STS, which takes as its domain of study the interaction between science, technology, and engineering on one hand and social and cultural forces on the other. The paper then turns to a brief assessment of PDI's major areas of success as well as those areas needing further attention before concluding with some thoughts on liberal education for engineers in the contemporary university context.

Contextualizing Engineering Education

Both design and the liberal arts have been extensively promoted as potential guiding paradigms for engineering education reform.[2] Each paradigm is touted for a variety of reasons, including its role in "integrating" students' educational experiences[3] and in providing context that makes otherwise abstract problem solving exercises more meaningful.[45] Design-based pedagogy is put forward as way to put to use engineering analysis as-needed and around "real-world" problems. Liberal arts courses are put forward as providing broader social context for engineering knowledge and, perhaps more importantly, as providing "vision" for directing engineering initiatives. However sensible, there is nothing inherent in either design or liberal arts pedagogy that necessitates integration or meaning-making within engineering education. In fact, when design courses or liberal arts courses are mere stand-alone courses elected, at best, idiosyncratically, it is just as possible that they further contribute to the compartmentalization and decontextualization of student learning. In every case, it is the specific mechanisms and context of application that makes either type of reform initiative effective. How interventions are conceptualized plays a supporting role.

Langdon Winner is perhaps best known for his seminal contribution to technology studies, "Do Artefacts Have Politics?," where he argues that, instead of being neutral, technologies fundamentally shape what people do, how people experience their worlds, and how people think about what is possible and desirable.[6] Hence, technologies have "politics" built in. While known primarily as an STS scholar and political philosopher, he has also published within the design studies community, his major publication extending prior work on the politics of technology. In one contribution to the design studies community, Winner calls for more systematic attention to, and more careful reflection on, how our built world fits with our body politic, or in other words how technologies fit with our overarching political ideals and goals.[7] According to Winner, "There is as yet no well-developed discipline or well-focused tradition of thought and practice that tries to do this, to specify which patterns of material, instrumental systems are well suited to different kinds of political conditions, especially ones worth sustaining."[8] It is not a new method that is needed, but a whole new approach bridging "political, spatial, and technical dimensions" of design.[9] Such inquiry is necessary interdisciplinary, since careful understanding of social worlds, technology, and their interactions is required. Since technology-making is not an end in itself, "It must always be seen in the context of broader political debates, goals, projects, and struggles."[10]

Winner calls his proposed new discipline "political ergonomics," and he builds a sketch of how political ergonomics might be approached by drawing together the main strengths of three distinct design traditions—engineering, statecraft, and architecture and urban planning. In this combined inquiry, engineering contributes practical material problem solving incorporating real-world constraints, statecraft contributes an understanding of political process and puts forward larger political goals toward which new innovation might strive, and architecture and urban planning contribute an understanding of the interplay between material environments and people's lived experiences. Thus, in analyzing the social significance of technology-in-the-making, political ergonomics sits at the intersection of social/political analysis and more synthetic design approaches that draw on whatever tools are available in the devising and implementation of future-oriented plans. This approach has significance for how we might think about a new liberal arts education for engineers: attending simultaneously to how artifacts carry embedded social relations and, therefore, to how the redesign of artifacts deserves attention to political controls as does any other wide-scale exercise of power.

Lucena applies similar insights directly to engineering education reform efforts, and highlights the potential of an STS-inspired integration of politics and culture. He laments, "[I]n fields such as science and technology studies and the history of technology, there is a long tradition of scholarship dedicated to study the relationship between engineering and culture. However, this scholarship has not been integrated into systemic engineering education reform."[11] Albeit at a very small scale, and applied only in one local context, PDI attempts to achieve exactly this integration.

Structure of Rensselaer's Product Design and Innovation Program

Rensselaer's PDI program was devised with no precedent to speak of. Rather, it was imagined within the unique field of constraints and opportunities afforded by Rensselaer's institutional context and the players at hand, including large programs in a variety of engineering disciplines and strong but much smaller programs in architecture and STS. In a university dominated by engineering students, faculty, and research programs, the PDI program created strategic openings for teaching STS content in ways congruent with the learning approaches and areas of interest typical of Rensselaer students. Despite this pragmatic prospect, however, the original motivation for the program was built more upon its intellectual promise than institutional opportunity. The brainchild of an anarchist philosopher, a feminist architect, and a design engineer committed to "the social side" of engineering, the program was conceptualized as radically interdisciplinary and, hence, with the potential to fundamentally change the quality of undergraduate education at Rensselaer.[12]

In its basic structure, PDI entails 1) a required design studio almost every semester as the unifying element of the curriculum and 2) a radically interdisciplinary approach to design education.[13] Studio work is complemented by additional STS core courses focusing exclusively on social analysis of science, technology, engineering, and design. The curriculum was originally set up as a dual-degree program, either between engineering and STS or between architecture and STS, but it has recently been reconfigured around a new STS degree—Design, Innovation, and Society (DIS)—which can be combined as a dual-degree with any other major on campus. Thus, DIS is the required core degree, and students can opt to major in DIS only or to combine it with various dual-degrees. From the program's first cohort in 1999, the vast majority of students has dual-majored in an engineering discipline, and a majority of those in mechanical engineering. As the program has gotten its feet, however, a steadily increasing number of students elect dual-degree options in areas other than mechanical engineering, including electrical engineering, management, computer science, communications, and others (see Table 1).

Entering Year	Total # Students	Mech Enrgr	Other Engrg	Non-Engrg Dual	DIS-only†
1997*	4	3	0	1	0
1998*	11	7	2	2	0
1999	24	16	6	2	0
2000	20	15	4	1	0
2001	15	15	0	0	0
2002	18	6	9	3	0
2003	18	16	0	2	0
2004	17	12	0	5	0
2005	26	23	0	1	2
2006	32	25	0	4	3
2007**	40	32	4	2	2

† Option first offered 2005
* PDI elected by non-first-year students; ** approximations

Table 1: PDI Program Enrollment

The PDI Design Studio Sequence

The PDI studio sequence serves as the primary integrating element in the program as a whole and is the main aspect of the program that students identify as being unique. As mentioned above, the majority of studios are team taught with faculty from engineering, STS/H&SS, design disciplines, and management in various configurations. Each studio in the sequence has its own focus areas, and each is designed to convey different technical, social, and aesthetic skills (see Table 2).

Studio	Focus Area	Skill Sets		
		Technical	Social	Design
Studio 1	Intro to Interdisciplinary Design	representational drawing, graphics software	needs analysis, design research	open-ended design, iteration, modeling, design notebooks
Studio 2	Product Development	design process, flow charting, CAD	interviewing, user observation	problem definition, design evaluation
Studio 3	Industrial Design	solid modeling, rapid prototyping	market & consumer research, usability	form & aesthetics
Studio 4	Varies by dual major (e.g., Intro to Engrg Design)	(e.g., engineering analysis)	(e.g., technical presentations)	(e.g., prototyping & modeling)
Studio 5	User-centered Design	hardware & software, electronic circuits	ethnography, product-user relationship, product identity	ergonomics, iteration, mock-ups
Studio 6	Tech Entrepreneurship	product & production economics	market potential, social effects/risks	moving product from innovation to market
Studio 7	Various by dual major (e.g., Inventors Studio)	(e.g., patenting design ideas)	(e.g., legal dimensions)	(e.g., creativity, iteration)
Studio 8	Varies by dual major (e.g., Capstone Design)	(e.g., engrg analysis for real-world problems)	(e.g., client relations, tech. presentations)	(e.g., design integration)

Table 2: PDI Studio Sequence

The use of design studios as a vehicle for teaching STS content and the social analysis of technology more generally is itself quite innovative. Social analysis and STS are typically taught in lecture/recitation format centered on reading, writing, and discussing course material, whereas design studios typically center on conceptualization and modeling of material objects of intervention, including often solutions to specific problems. PDI studios integrate both approaches. Like other studio environments, PDI studios tend to be project-centered, but the STS instructors have resisted letting go of their verbal, analytic approaches and have thus overlaid those approaches onto the "making" structure of the traditional studio format. The resultant is lots of time spent on "making" activities, interspersed with frequent, structured analysis that supplements, and sometimes even orients, the students' making activities. Hence, in the PDI environment, structured analysis is integrated into and responds to the student problem solving activity. Rather than being seen as distracting from the course's major pedagogical objectives—as the emphasis on social structures, value systems, and underlying assumptions often is understood in engineering design and in some architecture courses—STS analysis is built into the studio as a core component. Of course, other design studios, architecture studios in particular, engage in designing, analyzing, and evaluating interventions of various sorts from multiple perspectives, so this general approach is not entirely new.[14] But integrating social analysis in a systematic way is unusual,[15] and integrating STS/social science expertise into the day-to-day activities of a design studio, rather than bringing it in for occasional critiques and reviews, is even rarer. From the other direction, using the design studio format *as a vehicle for* teaching STS, is almost unheard of, with Rensselaer and perhaps the Danish Technical University being the only examples (and DTU's program is modeled, in part, on Rensselaer's program).

Radical Interdisciplinarity

The emphasis on interdiscplinarity in PDI is pervasive, evident in everything from our student majors to the faculty teaching in the program to the content, theoretical frameworks, and pedagogical approaches covered in the classroom. One of the most interesting (and administratively challenging) aspects of the PDI program is team-taught studio courses, where faculty from engineering, STS, and architecture/art/industrial design come together in various configurations. Roughly half of the studios are taught by interdisciplinary faculty teams, members of which share equal responsibility and administrative authority in the classroom. Another half of the studios are taught by individual faculty members, many of whom have interdisciplinary backgrounds. Also, the individually taught studios are divided up between STS, engineering, and other disciplines depending on the student's dual major option. Although the configuration of instructors has changed over time, a typical spread is represented in Table 3.

Studio	**Instructor(s)**	**Teaching Assistant**
Studio 1	Engineering, STS, Design	None
Studio 2	Engineering, STS	Engineering
Studio 3	STS (w/ engrg background)	STS
Studio 4	Interdisciplinary Engineering	Interdisciplinary Engrg
Studio 5	STS (w/ engrg background)	Engineering
Studio 6	STS (w/ engrg background), Management	Engineering
Studio 7	Engineering	Engineering
Studio 8	Engineering	Engineering

Table 3: PDI Studio Instruction (for DIS/Mechanical Engineering dual majors)

Interdisciplinary, team-taught studios provide a unique pedagogical opportunity for students, because instructors are forced to negotiate their (disciplinary) authority in the classroom, pushing them to reflect on what their approach offers to students' design process. In some sense, each instructor must be able to contribute to students' progress in order to maintain their authority (if not credibility) vis-à-vis other instructors advocating attention to other facets of design. In practice, this negotiation of authority is far from Machiavellian, so the "competition" among instructors is not acute (or even explicit). Instead, cooperation and mutual reinforcement are the typical modes of interaction.[16] Nevertheless, the subtle jostling among instructors is inevitable, and it appears to be generative for students, especially when students are empowered to participate in the "verbal jousting" among the various approaches to design.[17]

The interdisciplinarity of the PDI educational model is reinforced by the theoretical underpinnings that ground the program and that are used to teach PDI students about what "design" entails. The following section addresses these underpinnings and how major concepts from STS are leveraged in the studio to promote and enable interdisciplinary design inquiry.

An STS Approach to Design Pedagogy

STS theory is integrated into PDI studios in different ways by different faculty. This section provides a broad-brush overview of three approaches from STS that frame studio pedagogy.

How a Telephone Works

In opening his book *Designing Engineers*, MIT engineering and STS scholar Louis Bucciarelli provides a thought-provoking exercise on what it means to understand how something works.[18] When asked "Do you know how a telephone works?" most people assume the correct response—whether they answer yes or no—involves sound wave propagation, the vibration of diaphragms, the transmission of electrons, and other esoteric matters mastered only by physicists and engineers. If one does not "know" such matters, we generally assume, one does not know how a telephone works. But why is it, Bucciarelli asks, that physics is the ultimate arbiter of our understanding of the working of telephony, a multilayered, highly complex, systems-based, deeply socialized domain of human achievement? Somewhat ironically, Bucciarelli answers the question another way: How does a telephone work? Easy. You pick up the handset, dial the desired number, put the handset to your ear and mouth, wait for the answer on the other end, and then speak. This is, of course, precisely how a telephone "works," at least in the vast majority of users' *experience*. While skeptics may claim that Bucciarelli is describing how to "use" the telephone, not how it "works," that criticism misses his point, which is precisely that a technology's "working" is understood to mean its underlying physical interactions. We live in a world where how something works is based in physics; the experiential knowledge of operating a phone is (merely?) how it is *used*.

Bucciarelli's example is relevant to an STS approach to design because it opens up the contingency of both language and how it is that we "know" the world. Because such knowledge is always contingent (that is, such knowledge is meaningful according to shared understandings—understandings that could be different), it must be situated in its larger social context. "Workingness," therefore, is a social achievement every bit as much as it is a technical achievement. Importantly, this is not to say that social experience takes precedence over technical functionality, but that the two depend on one another to achieve an object that "works."

Complex Systems

Bucciarelli's analysis is derived from the "complex systems approach" in STS, which is also effectively brought into the PDI studio context. The complex systems approach has two important facets relevant to teaching STS in the design context. One facet stays true to Thomas Hughes's "complex technological systems" framework for studying the history of technology. This framework emphasizes the systemic nature of human artifice, where vast arrays of tools, techniques, and institutional arrangements work together and depend upon one another for their functionality.[19] For example, in our contemporary system of automobility, cars must run, but we also must have gasoline distribution infrastructure, traffic laws and road signs, and drivers' training courses. Efficient and reliable technical operation is given a central role in this analysis to be sure, but other forms of functionality must be included as well. In his seminal critique for the design profession, Victor Papenak provides a six-part "function complex," which is useful for extending our understanding of how a product functions both materially and socially. Included in his function complex are "use" functions (e.g., car as transportation, car as symbol of masculinity), "aesthetics" functions (e.g., car as elegant form), and "association" functions (e.g., PT Cruiser as invocation of 1930s gangster car).[20] By making the standard STS move of situating an object within its broader context, one can diligently draw out the connections and describe the mutual shaping between any given elements within the system.[21, 22, 23] This method of situating objects within various networks of connections, both social and material, is effectively mobilized in PDI by doing it "real-time," as students develop their projects and conceptualize potential solution paths or points of intervention.

Showing how products, in particular, are part of "socio-technical ensembles" is important in teaching PDI for two reasons. First, it pushes our students to move beyond their comfort zone in material products, and second, it keeps materiality as part of the equation. Thus, the second facet of the complex systems approach employed in PDI is derived from the first and entails a commitment to the *mutuality* of social and material innovation, an approach which does not lose the material in its quest to highlight the importance of the social. This commitment is especially important where products or other material interventions are intended to stimulate social change. Since our students are generally oriented toward product innovation and technological fixes to social problems, especially in their early years, we attempt to complement, but not replace, that orientation with attention to social innovation. Moving from isolated products to macro-level social contexts and socio-technical networks, and showing the complexity of connections attached to any single object, allows STS analysis to respond directly to students' interests and makes it more relevant to their domain of potential impact as engineers and product designers. Starting with "the object" gives our students something readily at hand, tangible, and focused to hold on to as they consider multiple, complex layers of material and social connections.

Focusing on the mutuality of social and material change enables a kind of back-and-forth analysis, a process that might be called "directed oscillation."[24] Directed oscillation refers to shifting levels of analysis, especially between bottom-up analysis of specific ideas intended to address specific components of a larger problem and top-down analysis that looks at the overarching problem definition and how it is broken into components. In the context of product design, this oscillation usually also includes movement between the material aspects of a proposed design and the various social contexts into which that object must fit. Because this multiple-contexts problem is usually too unwieldy to be "solvable" by any single design intervention, directed oscillation allows students to engage it intermittently but then retreat from it to find grounding in the designed object. Thus, there are two overlapping forms of oscillation: 1) between the specific designed object (or intervention more generally) and its various contexts and 2) between the material realm and the various social realms, including user perceptions, social values, organizational needs, etc. Again, starting with but moving beyond the object is especially important for Rensselaer students who are interested in and resonate with material objects and technology as potential change agents. Hence, PDI courses require students to scrutinize their fixation on technical fixes to social problems while not defining material innovation out of the equation for social change, which is especially important as we move from the design of the local object to the many broader forces impinging on it.[25]

Through attention to both social and material realms and to both micro and macro contexts of intervention, the complex systems approach has direct, immediate relevance to how and where our students envisage innovation. For example, students are frequently encouraged to move between the design of products and services as potential sites of innovation, and they are encouraged to combine products innovation with organizational innovation when existing organizations seem inappropriate to their product ideas. Similarly, laws and policies can be assessed, and even reimagined, as part of the students' design process. Helping students to come to appreciate the degree to which seemingly simple assumptions about where innovation happens—i.e., technology-based corporations—pervades their thinking is a significant challenge, especially given the degree to which mainstream economic assumptions underlie engineering education. Yet as soon as we reconfigure, say, mechanisms for achieving profitability, students' creativity flows in to fill the new space. Challenging typical assumptions about where innovation happens, in particular, allows students to imagine alternative organizational models that would enable alternative material configurations, and new product opportunities become evident as a result. More fundamentally, students move from recognizing how individual objects are situated in multiple overlapping socio-material networks to understanding that other elements of the network are potentially changeable as well. In other words, the larger contexts are no longer taken as "givens" and are themselves subjected to the designers' influence. In a way, this enables students to think of themselves more as "technology entrepreneurs"[26] or as Hughes's network builders[27][28] than as mere *product* designers.[29] This is especially well evidenced in the several of our graduates who have transitioned into their own start-up companies, including for-profit ventures with strong social and environmental visions.

Social Power and Marginalized Social Groups

A third pedagogical strategy that is increasingly integrated into the PDI program is attention to the needs of marginalized social groups and to addressing marginalization through design more generally. Several PDI courses are currently organized around designing for specific marginalized users, including various poor communities in the global South and elderly people and underprivileged, African American and Latino school children in New York's Capital Region. In some sense, designing for marginalized social groups is an extremely practical approach, because these user groups are typically underserved by existing designed objects, including consumer products. Hence, opportunities for innovation are generally easy to find. Furthermore, students can proceed with the design process very much as they would with any other project: identifying user needs, translating those needs to technical and other functional specifications, devising new products that meet the specifications, and then assessing the extent to which the new products meet user needs in the context of use. Applying this same general design process to very different user groups—and to user groups very different than typically undergraduate Rensselaer students—provides many learning opportunities, especially for understanding the (dis)connections between what Molotch calls the "product milieu"[30]—the vast array of material objects that fill our lives—and the experiences of marginalized social groups. As students come to understand the diversity of life experiences, they increasingly come to understand that, however laudable, designing a single product for "everybody" is untenable and probably even undesirable.[31]

Thus, attention to marginalized user groups has a variety of pedagogical benefits.[32] First, pointing out and analyzing whose needs and interests are accounted for by dominant design activity is generally enlightening to our students; they learn that a broad swath of humanity is not benefited at all from ordinary consumerist innovation and that some groups of people are even harmed, directly or indirectly, by products designed to service others' needs and desires. This lesson in economic inequalities and gender, ethnic, and class bias is eye opening for many of our students. Second, and probably more important, attention to needs of marginalized social groups helps our students escape their implicit assumption that other people experience the world very much as they themselves do. Systematically attending to specific social communities—communities that typically are underrepresented or absent among our student body—helps students realize the pervasiveness and profoundness of social differences in experience and thus in meaning making, especially in meanings surrounding the "benefits" of technology products. The pedagogical benefits of designing for "others," however, should not obscure the risks involved, both in terms of assuming one can easily come to understand other worldviews and in terms of implicitly endorsing a type of "charity" model of design where the fortunate and able design for helpless others.[33] Situating design for others within an analytic frame that incorporates attention to the structural features of marginalization helps to mitigate these risks.

A third pedagogical benefit of attending to marginalized social groups gets at the heart of STS's contribution to design: understanding how designed objects shape people's experiences in the world. This is another facet of the interplay between materiality and sociality, but with more explicit attention to social power exercised through material objects, or the "politics of artifacts."[34] Rather than attempting to understand these politics in a heavy-handed way, where one group deliberately and maliciously schemes to undermine another, the disconnection between the product milieu and marginalized groups' needs emphasizes how dominant design practice creates very different "forms of life" for different social groups. In critical ways, marginalization is not limited to transient social interactions, but is also concretized in material objects. Structures of marginalization, then, are both material and non-material, but they are always "structures" and not merely individualized practices and beliefs.

Assessment of PDI

Reflective Assessment

Having described innovative aspects of the PDI program, and focusing on the role of STS in that, the paper now turns to some reflections on what the PDI approach, at its best, contributes. Probably the most notable contribution is to suggest (and then show how) "things could have been different."[35] Such "things" include both material objects and the social circumstances underlying any given object's creation. Better still, such "things" also include socio-material configurations, not only the objects and the circumstances underlying them. In other words, the whole configuration of relationships that we understand as technological society could be different. We employ STS to insist that the configurations that dominate the world of design today—such as consumerist innovation of individual artifacts carried out by for-profit corporations to the primary benefit of economically powerful groups—need not be taken as "givens" in design practice. We allow students to "put into play" various material, political, economic, organizational, and cultural variables in their design work, and then we help them make sense of the implications of their design interventions in light of those variables.

In practical terms, the STS contribution opens the field of innovation potential because it allows students to think "outside the box" formed by current social circumstances and to challenge the assumption that these walls of the box are fixed. Although the thinking-outside-the-box cliché probably serves as much to disguise uncreative thinking as it does to stimulate it, the importance of understanding how problems are implicitly and explicitly bounded remains an important challenge underlying social-and-material innovation. Insofar as PDI achieves this, it does so by first identifying and then calling into question the dominant assumptions about social institutions that situate a given problem's solution-scape. Given our attention to the needs of marginalized social groups, the social relations surrounding problem bounding are even more important to account for. Bringing STS into the design context enables opening up an entire domain of assumptions limiting innovation, and it allows at least beginning to treat some of those assumptions as variables to be experimented with.

Consistent with the broader orientation of Rensselaer's STS Department, PDI takes the "things could have been different" approach in a specific direction: toward ends that are more democratic, more environmentally sustainable, and more socially just. The most direct way this is attempted is by seeking to empower marginalized social groups. Thus, in making things different, we aim to "make a difference."[36, 37, 38] This approach makes social (power) relations and social structures vital to students' design process, but does so without displacing the centrality of material interventions or negating the potential of material innovation to catalyze social change.[39] By applying STS methods and concepts in analyzing the social structures surrounding design processes and outcomes, we do not displace material, localized interventions. A subtle balancing act is needed to move between the local, material intervention and the many layers of interaction it has or is likely to have with other elements in the complex systems into which the local intervention fits.[40]

While STS scholars tend to be more fluent with social innovations—involving, say, policy making, professional cultures, or economic incentive structures—in the context of PDI, instructors keep the materiality of local interventions at the center of most project work. This challenges the tendency within STS, and in particular activist STS, to focus on the social structures that contextualize and give meaning to particular material artifacts.[41] In PDI, the social-centeredness apparent within STS counters the material-centeredness of typical engineering and architecture design approaches. Thus, structurally and pedagogically, PDI courses counter the tendency to exclude either the social (as in engineering) or the material (as in STS) components in the process of designing a better world. Even if changes to broad social structures are necessary to address marginalization, that is not to say that localized material interventions are not also necessary, either to catalyze or substantiate structural changes.[42] Whereas design students might otherwise be turned off by the social-centeredness of typically STS courses or by the tendency within STS to elaborate layer after layer of social problems without any apparent solutions, our approach keeps them invested in STS and the "social side" of technology and product design. In fact, it leverages their most immediate scope of influence, product materiality, for a more ambitious social agenda.

Having multi-disciplinary instructors as (ostensibly) equal partners in the structuring and execution of studio courses has also resulted in exciting pedagogical opportunities for students, because students could participate (directly or not) in the negotiation of expertise and relative authority between the instructors. In fact, one student referred to having two professors in the studio at the same time as providing "more than two times" the payoff for learning as the different disciplinary approaches were worked out *as part of the students' design process*. The student continued, "You learn their [approaches]. You get to weight their claims against your understanding of their [approaches]… Their disagreement is exciting because it questions the absoluteness of either approach."[43]

Challenges

While the PDI program has achieved remarkable success on many counts, it has also experienced important challenges and some disappointments. The most frequently voiced complaint by students is the lack of coordination among the various studios, where some material is redundant and other desired material absent. Lack of coverage is caused partly by the spread of expertise available among PDI faculty; while the program promotes radically interdisciplinary inquiry, it does not have access to all the domains of expertise needed to fulfill this goal satisfactorily. Most notably, design software skills are lacking among our instructors, and some instructors have found themselves relying on gifted students within their courses to take the lead on software training. The challenges of coordinating studio content, unfortunately, is a much deeper problem with administrative and disciplinary facets. While all PDI instructors are convinced of the value of interdisciplinary design, the relative emphasis of different approaches—and especially the relative emphasis of convergence and divergence within the design process—is continually negotiated within various team-taught studio courses.

Another shortcoming of the PDI approach is that students' scholarly identities are somewhat undermined. While their identity as "designers" (as opposed to "engineers"), and their identity as "PDI students" in particular, is both strong and coherent, this identity is that of "doer" more than that of "scholar." This is attractive to many undergraduates, but it has tradeoffs, including special difficulties for those students pursuing graduate school admission.

Administratively, the PDI program's challenges are far more insidious, with no immediate solutions evident. Most notably, the PDI studio is resource intensive. Studio teaching requires a much higher faculty-to-student ratio than typical engineering classes, a ratio higher even than typical H&SS courses. Team teaching further increases this ratio, but also adds inter-departmental, and more challengingly inter-school, coordination problems (e.g., who pays for what). Resource struggles between various departments and schools involved in the program have plagued the initiative from the beginning, and they show no sign of subsiding. PDI is also time-intensive for faculty, requiring more time in class, more time coordinating among multiple instructors, and more time interacting with (motivated but demanding) students outside of class.

Finally, PDI-type instruction and research faces subtle but pervasive prejudice by scholars within both engineering and STS. Written off by many as "applied" scholarship, design and interdisciplinary design especially, is seen as "soft," "non-rigorous," or otherwise lowly as opposed to "hard," "pure," high-status laboratory-based research. While the question of the relative status of different ways of knowing, and engaging, the world is clearly beyond the scope of the present analysis, it is relevant to highlight the parallel position of design educators within university engineering departments and that of STS scholars working on "applied STS" within the larger STS research community. In both cases, the privileging of experimental, laboratory-based research (or, in STS, "laboratory studies"[44]) is evident, a phenomenon with deep historical roots in engineering education.[45, 46] Ironically, however, it is precisely the lack of controls, avoidance of radical simplification in problem framing, and the need to question assumptions of design work—exactly what makes the resulting knowledge "soft"—that makes it hard to do and harder still to draw generalizable lessons from.[47] In the face of this challenge, an understanding of the relationship between social experience and relative authority of different modes of inquiry and different domains of knowledge is essential.[48] From some perspectives, this is the very essence of liberal arts inquiry: understanding the relationship between different human experiences and the contexts that give rise to them. Hence, the tools we seek to provide in PDI can just as well be used to analyze how engineering education reforms "work" or not within their larger social contexts.

Conclusion

By taking a close look at RPI's PDI program and how we use STS in educating future designers, this paper has provided one model for bringing STS into design. But in so doing, it has also identified some of the ways in which design activity challenges STS and bumps up against its boundaries. As with other forms of analytic inquiry—including engineering and aesthetic analyses—STS complements design by establishing solid mooring points in the broader world outside the design studio, and especially in a social world beyond the designer's immediate personal experience. If STS contributes to engineering education a broadened scope of understanding what is at stake in technology and product design—and perhaps even what it is that is being designed—then attention to design contributes something back to STS, namely a litmus test for its relevance as a constructive force. While I assume most STS *has the potential to be made* relevant to reconstructive activity, that is not the same as its *being made* relevant. I believe the potential for contributing directly to engineering design activity is, for the most part, latent in STS. The PDI program seeks activate that potential by integrating engineering with humanities and social science inquiry, providing a new model for liberal education for engineers.

Bibliography

1 Lucena, Juan C. 2003. "Flexible Engineers: History, Challenges, and Opportunities for Engineering Education." *Bulletin of Science, Technology, and Society*. Vol. 23, No. 6, Pp. 419-435.

2 Ibid.

3 E.g., Dym, Clive L., Alice M. Agogino, Ozgur Eris, Daniel D. Frey, and Larry J. Leifer. 2005. "Engineering Design Thinking, Teaching, and Learning." *Journal of Engineering Education*. Vol. 94, No. 1, Pp. 103-120.

4 Van der Poel, Ibo and Peter-Paul Verbeek, Guest Editors. 2006. Special Issue of *Science, Technology, and Human Values* on "Ethics and Engineering Design." Vol. 31, No. 3 (May).

5 E.g., Grasso, Domenico, Kara M. Callahan, and Sandra Doucett. 2004. "Defining Engineering Thought." *International Journal of Engineering Education*. Vol. 20, No. 3, Pp. 412-415.

6 Winner, Langdon. 1980. "Do Artefacts Have Politics?" *Daedalus.* Vol. 109, Pp. 121-36.

7 Winner, Langdon. 1995. "Political Ergonomics." In Richard Buchanan and Victor Margolin, Editors. *Discovering Design*. Chicago: University of Chicago Press. Pp. 146-70.

8 Ibid, p. 151.

9 Ibid, p. 165.

10 Ibid, p. 166.

11 Lucena, op. cit., p. 429.

12 Schumacher, John A. and Dean Nieusma. 1997. Unpublished manuscript.

[13] Bronet, Frances, Ron Eglash, Gary Gabriele, David Hess, and Larry Kagan. 2003. "Product Design and Innovation: Evolution of an Interdisciplinary Curriculum." *International Journal of Engineering Education*. Vol. 19, No. 1.
[14] Bronet, Frances and Linda Layne. 2007. "Teaching the Design of Feminist Technology." Paper presented at the 2007 Conference for the Society for Social Studies of Science, Montreal, Canada, 11-13 October.
[15] Frascara, Jorge, Editor. 2002. *Design and the Social Sciences: Making Connections*. New York: Taylor and Francis.
[16] Winner, Langdon and Mark Steiner. 2005. "Reflections on Rensselaer's Product Design and Innovation Program." Paper presented at the Engineering and Product Design Education Conference, Edinburgh, UK, 15-16 September.
[17] PDI student interview, 12 September 2007.
[18] Bucciarelli, Louis L. 1994. *Designing Engineers*. Cambridge: MIT Press.
[19] Hughes, Thomas P. 1987. "The Evolution of Large Technological Systems." In Bijker, Weibe E., Thomas P. Hughes, and Trevor Pinch, Editors. *The Social Construction of Technological Systems: New Directions in Sociology and History of Technology*. Cambridge: MIT Press. Pp. 51-82.
[20] Papanek, Victor. 1984. *Design for the Real World*, Second Edition. Chicago: Academy Chicago Publishers.
[21] Bruno Latour. 1987. *Science in Action: How to Follow Scientists and Engineers through Society*. Milton Keynes: Open University Press.
[22] Pinch, Trevor and Wiebe E. Bijker. 1987. "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other." In Bijker, Weibe E., Thomas P. Hughes, and Trevor Pinch, Editors. *The Social Construction of Technological Systems: New Directions in Sociology and History of Technology*. Cambridge: MIT Press. Pp. 17-50.
[23] Molotch, Harvey. 2005. *Where Stuff Comes From*. New York: Routledge.
[24] Nieusma, Dean. 2004. The Energy Forum of Sri Lanka: Working toward Appropriate Expertise. Unpublished Ph.D. dissertation, Rensselaer Polytechnic Institute, Troy, New York.
[25] Molotch, op. cit.
[26] "Technology entrepreneurs" combine two paradigms of innovation, one based in individual entrepreneurship and one based in cumulating technological advance. See Sundbo, J. 1995. "Three Paradigms in Innovation." *Science and Public Policy*. Vol. 22, No. 6, Pp. 399-410.
[27] Hughes, Thomas P. 1983. *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore: John Hopkins University Press.
[28] Hughes, Thomas P. 1989. *American Genesis: A Century of Invention and Technological Enthusiasm*. New York: Penguin Books.
[29] See, e.g., Ulrich, Karl T. and Steven D. Eppinger. 2004. *Product Design and Development*, Third Edition. Boston: McGraw Hill/Irwin.
[30] Molotch, op. cit.
[31] Nieusma, Dean. 2004. "Alternative Design Scholarship: Working toward Appropriate Design." *Design Issues.* Vol. 20, No. 3 (Summer), Pp. 13-24.
[32] Schumacher and Nieusma, op. cit.
[33] Marullo, Sam and Bob Edwards. 2000. "From Charity to Justice: The Potential for University-Community Collaboration for Social Change." *American Behavioral Scientist*. Vol. 43, No. 5, Pp. 895-912.
[34] Winner, 1980, op. cit.
[35] Carr, Edward Hallett. 1961. *What is History?* New York: Vintage Books.
[36] Nieusma, Dean. 2000. "Interdisciplinary Design Pedagogy: The Nature of Inquiry." Paper presented at the Conference for the Society for Social Studies of Science, Vienna, Austria, 28 September.
[37] Bronet and Layne, op. cit.
[38] Woodhouse, Edward, David Hess, Steve Breyman, and Brian Martin. 2002. "Science Studies and Activism: Possibilities and Problems for Reconstructivist Agendas." *Social Studies of Science*, Vol. 32, No. 2 (April), Pp. 297 - 319.
[39] Winner, Langdon. 1986. *The Whale and the Reactor: A Search for Limits in an Age of High Technology*. Chicago: University of Chicago Press.
[40] Thackara, John. 2005. *In the Bubble: Designing in a Complex World*. Cambridge: MIT Press.

41 Eglash, Ron, Jennifer L. Croissant, Giovanna Di Chiro, and Rayvon Fouché, Editors. 2004. *Appropriating Technology: Vernacular Science and Social Power*. Minneapolis: University of Minnesota Press.
42 Winner, 1986, op. cit.
43 PDI student interview, 12 September 2007.
44 Woodhouse, et al., op. cit.
45 Divall, Colin. 1999. "Fundamental Science versus Design: Employers and Engineering Studies in British Universities, 1935-1976." *Minerva*. Vol. 29, No 2, Pp. 167-194.
46 Dym et al., op. cit.
47 Cross, Nigel. 2006. *Designerly Ways of Knowing*. London: Springer.
48 Nieusma, Dean. 2007. "Challenging Knowledge Hierarchies: Working toward Sustainable Development in Sri Lanka's Energy Sector." In *Sustainability: Science, Policy, Practice*, vol 3, no. 1 (Spring). Pp. 32-44.