PRODUCT DESIGN AND INNOVATION: A NEW CURRICULUM COMBINING THE SOCIAL SCIENCES, DESIGN, AND ENGINEERING

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Abstract *¾ Product Design and Innovation (PDI) is a new undergraduate dual degree program at Rensselaer that seeks to educate students for careers in new product invention and development. PDI is a dual major program satisfying the requirements for the Bachelor of Science programs in both Engineering and Science, Technology and Society (STS). PDI prepares students to become innovative designers who can integrate contemporary technologies with changing social contexts for a new generation of advanced product designs. PDI aims to balance the traditional approaches of Architectural/Industrial Design and Engineering Design with the approach of Science and Technology Studies (STS). The backbone of PDI is the sequence of eight design studios, one every semester, that aims to integrate all three dimensions of the program. This paper will describe the PDI program, its goals, how it was formulated, and review experiences we have had in offering the three years of this innovative program. We will discuss how the design studio sequence fits together as well as present results from an outside assessment of the students in the program.*

Index Terms ¾ Design Studio Teaching, Multidisciplinary Design Education. Product Design, Science and Technology Studies.

BACKGROUND

Over the past eight years, professors from the Schools of Engineering, Architecture, and Humanities and Social Sciences (H&SS) at Rensselaer Polytechnic Institute have been working together to develop an inter-school, multidisciplinary design pedagogy. Based on our work, which included several co-taught design courses and studios, we have realized that a truly unique opportunity existed at Rensselaer to create an undergraduate product design program that (i) makes concrete progress towards realizing the disciplinary synthesis called for in these challenging times and (ii) can serve as a model for other design programs around the world.

Rensselaer's traditional strengths in its Schools of Engineering and Architecture, when combined with its strength in the Department of Science and Technologies Studies (STS) in H&SS, serve as the foundation upon which to base a totally new approach to product design education. STS includes faculty from six disciplines—anthropology, history, philosophy, political science, psychology, and sociology—all of whom work on understanding how science and technology shape society and how in turn society shapes science and technology. Supported in part by NSF, STS has also been working on its own focus on design as a natural complement to the traditional focus on design in engineering and architecture.

Our inter-school program in **Product Design and Innovation (PDI)** integrates these basic ingredients of design education, which we will elaborate on below:

- a sense of creativity and visualization;
- sensitive perceptual and communication skills;
- hands-on modeling and drawing skills;
- a design sense, so to speak, including an understanding of problem formulation, idea generation, and solution iteration;
- the ability to work well on teams with a variety of different people;
- technical skills, from using machine tools and rapid prototyping to computer aided design (CAD);
- an understanding of engineering science and manufacturing;
- an understanding of the basic disciplines in science and technology studies, featuring the art of reading a culture (ethnographic methodology);
- an understanding, specifically, of how a product is/will be situated in our lives, or rather, the art of reading a user;
- an ability to work at all scales of a product's context and life history; and
- the presentation skills to convey all of these ingredients at once.

The design experiences in the program cultivate in students the ability to function effectively in new situations

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and unfamiliar environments, to collaborate with a diverse constituency to formulate and analyze problems of varying complexity and to work individually or in teams to produce innovative design solutions that reflect this genius for integration.

The PDI program was begun with the incoming class of the Fall 98 semester and we have completed our first four years of the program. This paper describes the curriculum design for PDI, our experiences teaching this first group of students, and the results of some initial assessments of the students and program.

THE BASICS OF PDI

The institutional and administrative infrastructure for the PDI program is a dual-degree program jointly offered by the School of Engineering and the School of Humanities and Social Sciences. Students satisfy the requirements for the Bachelor of Science in either engineering (mechanical engineering or engineering science, a general engineering degree program) and STS. An option also exists between architecture and STS but for the purposes of this paper, we will describe only the engineering option. A complete description of the PDI curriculum template and the associated courses is available on line[8].

The core of PDI is *the design studio that students take every semester*, giving them a hands-on opportunity to bring together the two major curricula. The engineering science curriculum includes courses in engineering mechanics and electronics, energy, materials, and manufacturing. The STS curriculum covers the social and cultural dimensions of product development and innovation, including case studies of successes and failures. Through the design studios, students have the opportunity to translate into practical terms the diverse skills acquired in these two curricula.

THE DESIGN STUDIO SEQUENCE

The eight PDI design studios make up the core of the PDI experience. Three of the studios, *Introduction to Engineering Design* and a year long multidisciplinary capstone design experience, are existing courses taken by all engineering majors. These and the other specific studios developed for the PDI curriculum are described below...

PDI Studio 1

The PDI Studio I courses is taught in the first semester of the freshmen year and is co-taught with architecture, engineering, STS, and arts faculty. The course combines the first semester PDI students with the first semester architecture students and becomes the introduction to design practice and philosophy for both groups.

The central concerns of this semester were to open up ways of being in the world - through sensory awareness, through experimentation and physical engagement with artifact, site and program and through working methods for suggestive and precise communication. These studies are meant to encourage curiosity and risk while maintaining a concern for exhaustive rigor and investigation. The development of reflective judgment is a significant aspect of this course. Students are asked to reflect on the consequences of doing something in alternative ways, and determine who and what is affected by these design decisions.

Goals of the studio:

- To introduce the concept of Design: Learning by doing through hands-on exercises, synthesis, analysis; engaging the creative process though active learning, discovery, and reflection.
- To understand how design and creativity inform daily living.
- To be aware of the larger context - the social, cultural and political realms in which we design and build.
- To understand the relationships among disciplines that inform design.
- To learn the complexities of design through participatory student-faculty course development and collaboration.
- To reinterpret the condition of technology.
- To develop the ability to reflect critically on your own work and to evaluate consequences.

The first studio had two main projects, as well as a series of continuing exercises in computing, drawing and technology. We began the semester by using the telephone as the basis for a series of design exercises. These exercises explored representation of knowledge, modeling artifacts, redesign exercises, the cultural and social context for the object, and exercises in observation and ethnography. The second major project was the design of prototypes for a real community project; structures to aid farmers in the display and marketing of their products local farmers' market. The purpose of this project was to develop an expandable, collapsible, portable system of display, shelter, attachment, layout, etc. that could display, carry, or protect the farmer's produce, fliers, etc. and could be secured to the site (walls, ground, cars, bodies, etc.)

Over the course of the semester the students developed ways of understanding design in both an abstract as well as lived approach to engaging the environment.

The students kept notebooks of exploratory design sketches, notes/sketches on board critiques and public reviews, observations/drawings from the weekly exercises - (self-reflective journal keeping). Along with the drawings, three-dimensional model studies, design studies and presentation work done for the course was included in the portfolio in the form of photographs.

[8] http://www.rpi.edu/dept/sts/pdi/index.html

PDI Studio 2

PDI Studio 2 builds on the design exercises and experiences in PDI Studio 1. A major difference in this studio has been to focus on the development of individual basic design skills required for creative design work. These design skills fall into two categories: (1) skills for design expression (e.g., drawing, sketching, CAD, and modeling), and (2) skills in design development (e.g., problem finding and formulation, ethnographic methods, iteration of ideas, methods for creative thinking, and conversion of ideas into realizable designs). Of course, (1) and (2) are not entirely independent of each other (e.g., drawing or modeling may well become a way of developing a design). In addition, students are exposed to the basics of design presentation and the development of design portfolios.

Over the past 4 years, with better emphasis on skills development in the first studio, this studio has evolved into providing more emphasis on problem finding and definition, and on getting the students to begin to realize the impact they can have as designers.

The course is divided into two major projects. The first involves having the students define a problem that they would like to have solved within their rooms or living space that would improve their comfort, studying, etc (removal of roommates was not allowed). These problems are then turned over to another student in the class to solve, thereby making each student both a customer and a designer. The solutions are limited to the use of corrugated cardboard as the building material, and the designers as expected to deliver a working prototype by the mid-semester deadline. The prototypes are then “delivered” to each customer for their use and evaluation for the remainder of the semester. As part of this first project, besides design exercises in exploring cardboard as a building material, reading and discussions are held with the student on how design and technology has changed the way we live, and leverage that designers can have on their user’s lives.

The second project in the course this past semester was done with a local start-up company that was trying to define potential markets for their new video technology. This project was closer to a traditional product development exercise. Students were given assignments in researching the relevant technology and currently available competing products associated with company’s plans, and encouraged to define future (>5 years) products that would use the new technology the company was working on. Final designs were in the form of study models and rough technical prototypes.

PDI Studio 3

The third PDI studio is focused on the intersection between ethnographic techniques of data gathering and information technology (IT) design. Ethnographic methodology goes far beyond "user feedback." It includes participant observation, explorations of the social dimensions of technology, participatory design, and other anthropological perspectives that illuminate both the design process and the potential social impact of the finished product. IT includes both hardware and software, and ranges from new forms of communication (internet, intranet, infrared, etc) to new aspects of the human-machine interface (detection of body movement, sound, light, heat, etc). By training students to think about the synthesis between these two themes - ethnography and IT - they are able to explore mutual collaborations between product design and the knowledge of lived experience.

This semester's projects were based on design of educational technologies. The field site that allowed students to learn ethnographic skills was at an elementary school with over 90% minority children, which allows for consideration of wider social issues such as ethnic identity and economic class. We were fortunate in finding a class that allowed one-to-one pairing of children and design students. Design students conducted three phases of ethnographic experience:

- Participant Observation: here they actively participated with students in the classroom and playground. They were directed to record field notes that included learning challenges, emotional changes, spatial patterns, and other behaviors, and then follow up with an interview with the teachers concerning these observations.
- Design probes: this assignment required the creation of a design which would produce some response in students that illuminated the aspects of learning and play that would (hopefully) be manifested in their final design. Here the value of the ethnographic technique became clear, since most of their predictions and expectations were wildly off, and many new directions were inspired. By the time prototypes were produced, a keyboard device had turned into a floor mat; a series of weighted balls became a video game, and a video game had turned into a "sensor glove" that turned light patterns into sound.
- User feedback: These working prototypes were brought back to the school for a final round of observation and refinement. Feedback from teachers on various aspects of the designs, from safety concerns to special learning needs, was also invaluable in the final assessment.

PDI Studio 4

PDI Studio 4 is actually an existing course in engineering, *Introduction to Engineering Design (IED)*, which is taken by all engineering majors in their second year. IED introduces the engineering design process to engineering students who work in teams of 7-8 on very open-ended design problems provided by the faculty. Examples have ranged from the design of a Frisbee™ launcher to the design of exhibits to teach science and technology to middles school children. The student teams are required to define, develop, design and build a working prototype of their design within the 15-week semester. The designs typically are a mix of mechanical and electrical

systems, and are put on display at the end of the semester in an all day exhibition.

A major piece of the IED course is specific instruction on working and leading teams. Fully 25% of the course time and grade is devoted to teaching the students the fundamentals of teaming, leadership, diversity, conflict resolution, and how to recognize and deal with different work styles. More details of this material can be found in [1].

PDI Studios 5&6

In the third year of the program, Studio 5, Industrial Design, is jointly offered with Architecture and presents the traditional focus of Industrial Design in reconciling form and technology. Studio 5 provides an opportunity for students to compare how PDI is differentiated from the typical concerns of industrial design and assemble ideation and visualization tools towards defining a personal design methodology. In the fall of 2001 the studio undertook a range of projects with group and individual components. The first project, *Fold, Spindle, Mutilate* drew upon previous experience in working with corrugated cardboard furniture as students explored how a desk and chair might be designed and fabricated in thin sheet materials for use in developing nations. In the second project, *Bluetooth Kitchen*, students examined the potential of wireless communication to transform work in the kitchen. Teams researched thermal, cleaning, preparation and coordination tools and then worked together to design a unified system. Issues of user interface, safety and the changing demographics of the modern American family were important components of the project. In the final project, *Home Alone Too*, students confronted the problems of older Americans wishing to remain in their homes and to explore a combination of products and services that might address the special needs of this group.

PDI Studio 6 focuses on new technologies and their potential application in new products and services. Originally two interrelated projects were conceived to explore social, environmental and land use impacts as byproducts of new technologies. In the first project, eVelo, the studio would work as a "development team" (modeled on Nissan's California Studio) to assess characteristics of a solar versus a biomass (fuel cell) powered electric commuter scooter. In the second project "cybersprawl" students would examine how devices like the cell phone support suburban sprawl and examine how new technologies might alternatively serve urban cores such as that of Troy. As the complexity of the electric bike became apparent, the concerns of the two projects were merged and students developed a center in downtown Troy where the electric bikes could be marketed, partially fabricated, assembled (using local labor), stored, recharged, and eventually, recycled. A ride simulator configured each bikes physical dimensions and performance characteristics to their potential rider. Students conducted focus groups and produced a website and animated TV commercial as part of their marketing effort.

PDI Studios VII and VII

The final two design studios combine to be a yearlong design experience that the students can fulfill in one of two ways. The first is to participate in the *Multidisciplinary Design Lab* at Rensselaer which involves multidisciplinary teams of students solving industry sponsored projects. The teams are made up of engineering students from several different disciplines, depending upon the needs of the project. The project ideas are provided by industry who provide both monetary and some technical support. The student teams become self-directed design teams who are required to define their project schedules, work with the sponsor in defining deliverables, and "contract" with faculty for consulting help in the form of instruction to fill in gaps in background that the students are likely to find. For the PDI students, this has become an opportunity to develop their leadership skills, and to learn how to innovate in a sometimes very constrained situation. Experience so far, while very limited, seems to indicate that PDI students tend to gravitate to the leadership roles and are often the driving influence in trying to keep the design ideas from converging too fast.

The optional opportunity for PDI students in their senior year is a course entitled, *Inventors Studio*, which has been created at Rensselaer to allow students to pursue their own ideas within a credit-bearing course. Students are encouraged to come to the class with their own ideas for products or inventions, but anyone is welcome and those without their own projects are recruited to work on other students' ideas. The students are encouraged to develop their ideas to patentable form, and help is provided for students to create their own patent applications. For some PDI students, this option has provided an opportunity to pursue ideas that may have begun as a project in a previous studio and gives them an opportunity and resources to bring the ideas to further maturity.

ASSESSMENT OF THE PDI PROGRAM

In the 2001-02 academic year, the PDI program directors undertook an assessment of the program in an attempt to determine if we had made any progress on our overall goals of educating a new type of design student. There were two major components of the assessment, assessment of students and assessment of the program. A focus group study was undertaken as a means to benchmark current PDI students with their non-PDI counterparts. To assess the program, an external panel of design and STS educators was formed to study the program and make recommendations to the directors. The following is a summary of the findings of these two assessments.

Student Assessment

In Fall 2001, which represented the beginning of the fourth year of the program, an outside consultant was engaged to develop a focus group assessment of the current PDI students. The purpose of the assessment was to provide feedback to the directors of the program on the content and structure from the students' viewpoint, to determine if the goals of educating a more creative, socially aware designer were being met, and to provide material for the external reviewers.

Approximately 70 PDI and 70 non-PDI students were recruited for the focus group study. The students were drawn from all classes. The non-PDI students were drawn from several different engineering disciplines with the majority from mechanical and aerospace engineering. The focus group was a combination of quantitative and qualitative assessments. Six focus group sessions were held, three with PDI students only, and three with non-PDI students only. The focus group session consisted of a group discussion, filling out surveys, and participation in a short group design exercise. Each session was audio and video taped for analysis later on by the evaluator.

The group discussion focused on student backgrounds, their expectations for their education, why they chose engineering or PDI, what they liked about their education, and suggestions for improvement of the program, either engineering or PDI.

The design exercise was developed by the PDI directors to determine if PDI students approached a problem in a different way than a typical engineering student might. Students were given an ambiguous problem and asked how they would approach the problem, then asked how they might solve it. The problem posed was, *"If you were given the problem of redesigning a tall kitchen shelf for a grandmother who needed help getting things in and out of the upper shelves, what question would you want answered first?"* After discussing the issue amongst them, the students were then asked, *"How would you go about solving the problem?"*

The quantitative assessment was done using three instruments, the *Science Research Temperament [SRT] Scale of Creativity* [2], *Creativity* [3], and a social awareness questionnaire created by the PDI faculty. The first two instruments are described in the references, the third consisted of seven design problems, each of which had three multiple-choice answers which were all possible answers but one choice was meant to determine if the student had taken into consideration the possible array of social and ecological factors that might enter into the design.

Student Assessment Findings

By the quantitative measures of creativity used in this study, the PDI students are a very creative group. Table I provides the results of the SRT test. It's interesting to note that in the validation of this measure, the upper 10% of the most productive research workers scored 24.4. The results also show that the PDI students significantly outscored the non-PDI students.

TABLE I
SRT CREATIVITY SCORES FROM STUDENT FOCUS GROUPS

Year	PDI Students	Non-PDI Students
Freshmen	23.87	18.78
Sophomore	23.09	20.39
Junior/Senior	26.4	18.33

The *Creativity* test consisted of asking the students to generate uses for each of three drawings of objects given to them. The number of uses generated per student for all three drawings was the score on this test. Again, in this test, the PDI students generated significantly more uses for each object than did the non-PDI students (Table II).

TABLE II
CREATIVITY TEST SCORES FROM STUDENT FOCUS GROUPS

Year	PDI Students	Non-PDI Students
Freshmen	15.9	10.6
Sophomore	19.3	8.9
Junior/Senior	19.4	18.6

The results from the Social Awareness Questionnaire showed no significant difference between the PDI and the non-PDI students. This questionnaire was developed without any formal validation study and is probably inadequate to draw any conclusions from.

The Qualitative Assessment was performed by the consultant based on an analysis of the focus group transcripts. In the Design Exercise, a number of factors were investigated including how well they defined the problem, how well they worked within the group setting demonstrating good communication and leadership skills, how many different solutions were generated, the breadth of solutions considered and the originality of the solutions, and the degree of social awareness that was included in the discussions. The following conclusions were drawn from an analysis of the sessions

- At all levels, the PDI students showed an increased ability to approach the exercise in a systematic fashion focused on problem definition.
- The PDI students produced more solutions (7-10) than the non-PDI students (4-7)
- The PDI solutions tended to have more variety and innovative aspects.
- The PDI students showed more awareness to social factors, particularly those related to age, health and psychological factors.
- There was a slightly stronger tendency for the PDI students to become leaders during the Design Exercise.
- The PDI students had better communication skills, overall, than the non-PDI students.

FUTURE WORK

The PDI program has completed its first phase and graduated its first class. While we believe that the program is innovative and well conceived, there is always room for reflection and redesign. When we started we had a concept for how the eight studios would fit together with the first four studios building design skills, and the last four using these skills to solve increasingly complex design problems that were challenging both technically and socially. As good design practice dictates, we now must look back and see how well we accomplished what we set out to do and assess our assumptions. The initial assessment of students reported above provides some reason for optimism; however, there are still holes to fill.

In March 2002, using an accreditation model, a review panel was formed from faculty in well established and prestigious programs in both design and STS programs from around the country. The panel was provided with course syllabi, descriptions of the program, examples of student work, faculty resumes, and then visited with faculty, administrators and students while here for 2 days. Their report provided an important outside look at where we are and what we should consider going.

Some of the major findings of the panel are listed here,

- The vision and mission of the program still needs more clarification. A solid statement of our core concepts which are articulated through the studios needs to be better defined.
- The PDI degree program needs to be more flexible. The dual degree in engineering and STS leaves very little room for electives. We should consider how we can add some more options within the program and consider whether 8 studios are too many.
- Expand the PDI program into graduate level study within the STS department. The STS M.S program could provide a curriculum aimed at preparing STS students for positions in industry aimed producing specialists in need finding and design testing.

A significant effort is now underway to consider how to respond to some of these findings.

In the end, there is a significant opportunity here to define how engineering education can be changed. In many curriculums and programs around the world, the education of engineers provides very little opportunity for students to be innovative, creative, and to make in-depth explorations in areas of inquiry outside of engineering and science. As we begin the 21st century, engineering disciplines are under attack; the need for specialization is being replaced with a need for interdisciplinary. Additionally, engineers are being called upon to be more accountable for their work; the need to communicate technical ideas and solutions, the need to work within new environmental, economic and social constraints is increasingly becoming a part of contemporary engineering practice. These elements need to find their way into the engineering curriculum. The PDI program provides an example of how the technical, creative, and social elements of an education can be combined.

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