Learning Across Functional Silos:
Lehigh University's Integrated Product Development Program

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Abstract

Since 1994, Lehigh faculty and students have been piloting a new educational initiative that at its full implementation in the year 2000 will involve over 1200 undergraduate students. Peter Likins, the President of Lehigh, has called the IPD program "one of the most profound curricular changes in Lehigh's history." The program's unique features include truly interdisciplinary teams of faculty and students from three of Lehigh’s colleges—Business, Engineering, Arts & Sciences—working together on industry-sponsored projects integrated vertically throughout the students’ educational experience, ranging from pre college through undergraduate and graduate degree programs. In November, 1996, the program gained national recognition as the winner of the 1996 Curriculum Innovation Award from the American Society of Mechanical Engineers.

Introduction

Faculty, students and industry partners at Lehigh University are fundamentally restructuring and rethinking curricula across three of Lehigh's colleges, the College of Arts and Sciences, the College of Business and Economics, and the College of Engineering and Applied Science. The catalyst is the new Integrated Product Development (IPD) Educational Program, which President Peter Likins has called "one of the most profound curricular changes in Lehigh's history." IPD is a sequence of experiential product design courses that complement and enrich—rather than replace—existing disciplinary majors. The program stresses a hands-on approach to prototype and product development. Teams of business, engineering and design arts students work together on real industry-sponsored projects to produce technical and business feasibility studies, mockups of design ideas, working prototypes and business plans. The students come to understand the interdependencies and multidisciplinary, team-oriented nature of work and decision-making in today's global business enterprise. This actively engages them in developing the skills necessary for a lifetime of learning and leadership.

This paper outlines the goals, history, and structure of the IPD Program. It concludes by exploring the major issues and lessons learned in program implementation. The three faculty authors have been the lead participants in each of the three participating colleges. In addition, to illuminate how the program functions in practice, the paper also includes a brief discussion of one student's experience, authored by a (then) senior undergraduate who completed the two-semester "Capstone IPD Projects" portion of the program.

The main goal of Lehigh's Integrated Product Development Program is to enable graduates to move more rapidly along their chosen career paths, graduating both competent in their functional disciplines—whether engineering, business or design arts—and better prepared for long-term success. In restructuring the curricula to provide flexible integrated curricular experiences, faculty and industry partners have insisted on maintaining the rigor and strengths of traditional curricula in developing discipline-specific technical skills. Indeed, the program does not reduce the number of courses or credit hours required in those disciplines. At the same time, however, by working in interdisciplinary teams on industry projects throughout their undergraduate program, students develop skills to help them become more multi-functional, self-directed, and team-oriented. The program also emphasizes written, oral and visual communication.

The planning for Lehigh's IPD Program started in 1991 with the first implementation in the spring of 1994. By 1997 participation had grown to 37 faculty members and over 200 students annually.

The Need for IPD

Corporate leaders, recruiters, and researchers studying the learning process have for decades been calling for fundamental reforms in the way undergraduates are taught. The IPD Program is designed to squarely address the major issues identified by a seemingly endless series of both academic studies and blue-ribbon panels.

For example, a 1995 study of the corporate view of the readiness of today's college graduates, done by the Business-Higher Education Forum, a group of business and academic CEO's from major US firms and universities, found that:

> "Corporate leaders agree that [college] graduates are deficient in a number of areas, including leadership and communication skills; quantification skills, interpersonal relations, and the ability to work in teams . . . . In the face of global competition, higher education is behind the curve—unable to respond quickly and trapped in a discipline-bound view of knowledge. "[1]

Similarly, in 1994 the American Society for Engineering Education convened a blue ribbon group of industry leaders and engineering deans who identified twelve key areas for reform [2]. Among them: leadership, communication, integration of knowledge across the curriculum, a multidisciplinary perspective, and teamwork, active learning and collaboration. Very similar reform needs for interdisciplinary synthesis, critical thinking, interpersonal and team skills, and hands-on problem solving were identified since 1993 by, among others, the Association for the Study of Higher Education [3], the Synthesis Coalition [4], the Education Commission of the States [5], and the Foundation for Critical Thinking [6].

In addition to these general calls for reform in undergraduate education, educators have stressed similar curricular deficiencies specifically in both engineering and business management. For example on the engineering side, in 1989 the National

Advisory Group of Sigma Xi, the Scientific Research Society, identified a number of typical features of undergraduate curricula that inhibit learning and drive away potential engineering and science students [7]. Among these negative features are large class sizes and impersonal relationships with faculty, failure to stimulate and engage students in the learning process, pedagogic emphasis on memorization rather than analysis, synthesis and critical reasoning, segregated disciplinary course offerings without emphasis on why they are relevant or how they are related to each other, and no introductory offerings about what professional problem-solving entails or its constraints. The importance of an active, project-based, collaborative experience and interdisciplinary teaming is a constant theme in many reports specifically on design education [8-15], including from the National Research Council [8] and National Science Foundation [15]. In business and management there has been a parallel flood with remarkably similar emphases [16-22]. Indeed, the literature on the value of multidisciplinary collaborative project-based curricula date back more than 25 years [23].

In response, national professional organizations and academic accrediting bodies such ABET [24] in engineering and AACSB [25] in business now actively encourage curricula that are more integrated and cross-disciplinary. ASME in particular has encouraged the integration of design throughout the engineering curriculum [26]. A number of colleges and universities now offer multidisciplinary design courses for engineering students. As far as we are aware, however, none of these programs are comparable to Lehigh's IPD in terms of size and disciplinary scope. Penn State, the University of Washington and the University of Puerto Rico, for example, have NSF-funded "Learning Factories" where teams of engineering students apply multidisciplinary problem-solving skills in design projects [27, 28]. All Drexel senior engineering students participate in year-long team design projects [29]. MIT Sloan School graduate students can work on collaborative project teams with design students from Rhode Island School of Design [14]. As overviewed in [30], collaborative team-based product design courses of various flavors are also offered at Auburn, Carnegie Mellon, Delft University of Technology, Ohio State, Stanford, Syracuse, University of Michigan, California State Polytechnic University, Berkeley, University of Oregon, University of Texas, University of Toronto and the University of Vermont.

Not only are such active, interdisciplinary collaborative offerings increasingly popular, educational research evidence [31-39] strongly suggests that they are more effective than traditional curricula from the perspective of developing higher-level cognitive skills such as critical thinking, communication and teamwork. As one major literature review [31] put it:

> "Over 600 studies have been conducted during the past 90 years comparing the effectiveness of cooperative, competitive, and individualistic efforts. These studies have been conducted by a wide variety of researchers in different decades with subjects of different ages, in different subject areas, and in different settings. More is known about the efficacy of cooperative learning than about lecturing, departmentalization, the use of instructional technology, or

> almost any other aspect of education. The more one works in cooperative learning groups, the more that person learns, the better he understands what he is learning, the easier it is to remember what he learns, and the better he feels about himself, the class, and his classmates. Cooperative learning, although not the easiest way to teach, can revitalize students and faculty by providing a structured environment for sharing some of the responsibility for learning. Through working together to learn complex conceptual information and master knowledge and skills, students learn more, have more fun, and develop many other skills, such as learning how to work with one another. Faculty, meanwhile, must provide the foundation and learning structures to guide their students in this new learning experience."

Program Structure

Lehigh's IPD program is unique in structure and combination of features. Elements of the program exist at other institutions, but we are unaware of any program that combines them, particularly at the undergraduate level. ***First***, Lehigh's IPD is fundamentally interdisciplinary. It draws students, faculty and courses from the College of Arts and Sciences, the College of Business and Economics, and the College of Engineering and Applied Science. ***Second***, IPD integrates multiple levels. The undergraduate curriculum begins with an interdisciplinary freshman projects course, followed by discipline-specific course sequences, and culminates in an interdisciplinary capstone projects course. IPD also encompasses pre-college outreach and graduate programs. **Figure 1** is a schematic of how we envision, vertically, the multiple levels, and horizontally, the interdisciplinary approach. ***Third***, IPD students and faculty collaborate closely with industry throughout the program, from planning, mentoring, sponsorship and an industry advisory board, to providing real design, manufacturing and commercialization projects for student teams to tackle. This collaboration ensures that IPD remains focused, properly funded and responsive to industry needs. Indeed, the program would not be possible without the participation and commitment of our corporate partners (Table 1) across a wide spectrum of industries and companies, from global industrial giants, to mid size firms, to some of the smallest companies in America. Industry-sponsored products developed by the student teams require analysis of technical and economic feasibility as well as with aesthetic, ergonomic, safety, environmental, national and international considerations.

[Figure 1 and Table 1.]

Horizontal Interdisciplinary Integration

One of the basic tenets of the IPD approach requires students to work in cross-functional teams. The IPD pilot expanded this concept to include faculty from all three colleges working together to develop complementary curricula. The IPD program combines resources to redefine existing courses to help implement the IPD initiatives within each college.

The *College of Engineering and Applied Science,* through the Department of Mechanical Engineering and Mechanics (MEM), is spearheading the IPD integration throughout the undergraduate and master-level curricula. This effort is described below. The college is piloting a new ***Freshman Design Projects*** for all engineering majors with students from Arts and Sciences and from Business taking the course as an elective. The interdisciplinary teams of students reverse engineer common products such as mixers, baseball bats, CD players, etc. The methodology focuses on the "why" from various perspectives: design, manufacturing, aesthetics, material and business. The students must disassemble, describe, reassemble and describe possible ways to improve the product, while investigating the business environment and technical background.

The ***Industrial Design Initiative*** is a joint engineering and arts development of a minor program for those engineering students interested in IPD and industrial design. Luckily, this initial effort is being funded by a Lehigh alumnus, and joint proposals to develop additional laboratories and curriculum have been initiated.

All engineering departments require a capstone design project experience. However, these ***Capstone IPD Projects*** have been at different times in the curricula and given different credits depending on the department. Lehigh’s six engineering departments have begun to coordinate both timing and credits, and to embrace the IPD philosophy in order to get ready for the roughly 200 capstone students annually from business and arts.

The faculty from the *College of Business and Economics* voted to add a three course, nine-credit sequence in Science and Technology Awareness. It has evolved to include ***Freshman Design Projects***, a basic science or a fundamentals of engineering technology elective, and ***Capstone IPD Projects***. The freshman and senior projects are team taught with the faculty and students from all three colleges. Because only the Department of Mechanical Engineering and Mechanics has fully implemented IPD, all business students cannot yet be accommodated. As of 1997, except for the science requirement, the Freshman and Capstone courses remain electives for business students.

The College of Business also helps attract industry sponsored projects through its Small Business Development Center (SBDC), the Management of Technology (MOT) program, the undergraduate Lehigh University Management Assistance Counseling (LUMAC) program and the Center for Innovation Management Studies (CIMS). In the past these activities did not include technology assistance. Now with the inclusion of both undergraduate and graduate engineering students, these programs can provide expanded service to their industrial clients.

The ***Industrial Design Initiative*** in the Department of Art and Architecture in the *College of Arts and Science* is the newest aspect of the IPD program. With funding from an alumnus, a five to seven course sequence of industrial design courses is being developed to prepare engineering students to deal with the issues of aesthetics, man-machine interaction, safety, ergonomics and visual communication. The courses being developed focus on the techniques of sketching, line and form, color and light theory, model making, computer animation and photorealism, etc. As this program expands to include undergraduate and graduate industrial design majors, their special skills are expected to have an immense impact on the IPD project teams. All arts and science students are encouraged to participate in both the freshman and senior level IPD projects as part of their elective program.

Vertical Multi-Level Integration

The second tenet of the IPD program is the vertical integration of selected pieces of the industry projects into graduate, undergraduate or pre-college programs in order to infuse the student's learning environment with real-world experiences while expanding the human and technological resources available to project teams. In this approach, the ***Capstone IPD Projects*** teams might include a graduate business student and MEM graduate student working as project management and technical mentors with undergraduate teams. Junior students may be analyzing the competitive environment and devising marketing strategies while teammates are manufacturing various components of the proposed product, while sophomores develop complex assembly models or make physical prototypes in the MEM machine shop. Freshman teams can investigate competitive products while working with local high schools participating in a university-sponsored regional competition. In this scenario project, team and curricular management, and interdisciplinary communication are paramount.

Project oversight and curricular integration is the faculty responsibility, along with project and team selection, and is coordinated by a seven person faculty steering committee. The student teams manage themselves: identifying tasks and then assigning responsibilities and time lines. Weekly progress briefings with engineering, business and industrial design faculty and, when possible, the company sponsors, provide direction and insure schedules are met.

Industry-Sponsored Capstone IPD Projects

Based on many years of working with industry sponsored projects, a critical component to success of the IPD Program is the active participation of the industry sponsor both in project selection and in providing the student teams product, marketing and manufacturing information. The project must be tractable and not of critical strategic importance. We look for "back burner" projects or those of possible future importance. A project manager from the sponsoring company receives a syllabus and text, and is asked to be available to a student contact two hours per week usually via e-mail and phone, and, if possible, to attend periodic design reviews and to review progress reports.

Companies are asked to provide $5,000 per project and to sign a disclosure form allowing the University to print the company name, project title and abstract. Students and faculty often sign a three year nondisclosure form for the protection of the sponsoring company.

Ownership rights to developed technologies are coordinated by Competitive Technologies of PA, Inc., a wholly owned subsidiary of Lehigh University that is responsible for the commercialization of university intellectual property. From experience, companies' needs and policies differ and each requires up-front consideration of ownership issues.

In the steady state model, we anticipate undertaking approximately 50 projects each year with two to four competing teams working on each project. Each team is expected to consist of at least one student each from business, engineering, and design arts.

Example Project and One Student's Perspective

As one example of the more than 20 projects completed annually, a six member group of students recently teamed with Neo Products, a small entrepreneurial firm that manufactures contemporary electric stringed instruments made of engineering materials. The client had an exciting novel product and strong artistic and industrial design expertise but struggled with structural design and analysis and had little experience with marketing and financial planning.

A typical Neo Products instrument is a plastic neon-filled electric violin. The Neo Products project came to the attention of the faculty through Lehigh's Small Business Development Center and the company was funded by the State of Pennsylvania's Northeast Tier of the Ben Franklin Technology Assistance Program, located at Lehigh.

In a very personal way, the team of faculty, students and industry partner faced the sink or swim business challenges of project and time management, team communication and leadership throughout the multidisciplinary process of identifying target markets, determining customer needs, benchmarking competitive products, evaluating marketing and financial strategies, generating concepts, developing a detailed product design, and prototyping and testing it. The industry sponsor received a working prototype along with written and oral reports that described technical and financial feasibility.

Heather Beam, a 1996 Lehigh graduate, in the spring of 1996 had just completed working on a project for Neo Products in the ***Capstone IPD Projects***. ***Capstone IPD Projects*** is a two-semester sequence which requires weekly informal project reviews, four formal oral presentations, two final (and four draft) written reports, and a poster for each project at the annual day-long poster session. Sponsors, faculty, other students, local schools and media are encouraged to attend all public presentations. Beam describes her experiences this way:

“It was clear [the owner] was strong in industrial design and the arts. What he lacked was a solid background in technical, financial and marketing areas. From an engineering perspective the necks of his violins were warping. Also, he was having a hard time breaking away from the conservative old-fashioned perception of violins and classical music. These were the major areas of concern we tackled.

“Our main goal from the start was project management. We were given brief descriptions of available projects and we chose which one we wished most to work on and which students we wished to work with. Next, we identified our tasks for the semesters ahead of us, we set goals and objectives that (we hoped) were feasible in the time we had. Our team had two business students and four engineering students [this was prior to design arts students joining the IPD program]. Finally we were assigned two advisors, one from the engineering college and one from the business college. We met for weekly progress briefings, meetings that I understand are consistent with the proceedings of a team project in industry, which meets occasionally for design reviews and progress updates.

"Once we assigned responsibilities we were ready to tackle the several tasks ahead of us. **Table 2** represents our tasks and deliverables for the entire two semesters. Discussing briefly a few of the tasks most important to our project, to begin we all contacted violin players of all types, in many cases through the Internet. This allowed us to compile our list of customer needs, which led to our most important specifications and constraints. As mentioned, Neo Products was experiencing marketing problems because of the entrenched view of classical musical instruments. We decided our market was geared towards intermediate to advanced violinists in the areas of rock, country and jazz music. Of course we completed the list of tasks and midway and at the close of each semester we presented oral and written reports to the faculty, fellow students, and the sponsor company.

[Table 2.]

“At this point it was clear to our group that this program was a first for all of us and we were learning several important lessons from these new experiences. First of all, we had never teamed with anyone from a different college. As an engineering student, I personally had certainly never worked that closely with business students. Also, having one single project with one single project team for an entire two semesters was something new. Finally, being evaluated solely on the performance of a team was certainly a first and would introduce us all to the importance of reaching project goals regardless of whether or not a team member holds up his or her end of the bargain.

“Through all of this we learned several valuable lessons as undergraduates about ensuring team project success. Some problems we had specifically within our group that led to these lessons were, first, communication problems. Challenges of team communication needed to be addressed from the beginning and each member needed to understand the importance of including the entire team in any thought or idea. Second, when all of the team members assume a leadership role, this can cause problems. We experienced this to some degree and learned that each of our ideas could be equally beneficial to the project. Third, if a team member is not carrying his or her weight, the rest of the team must make up for those discrepancies. The team must realize the importance of meeting goals on any terms. Fourth, time management is an area in which we should have placed more emphasis from the beginning. Because we did not, we found ourselves struggling at times to reach goals we had set.

It is clear now that having 20-25 percent of our time devoted to our project (due to other obligations for classes, etc.) parallels that of industry where team members have other responsibilities and may quite possibly be working on other projects as well.

"Finally, due to the nature of the problems, we were forced to be immersed into these business realities and essentially made to sink or swim. Fortunately or unfortunately, we managed to tread water. I can also say that industry people are probably glad we struggled with this and learned these lessons now as opposed to in industry and on their time!"

Example Vertical Integration: Neo Products Projects Continued

While seniors on Beam's team worked on the economic and technical feasibility, freshman teams performed destructive and nondestructive tests and did background research on the musical instrument industry and market. Sophomore ME students constructed detailed assembly models and detailed drawings using the latest CAD/CAM software from SDRC (I-DEAS) or from GM/EDS (Unigraphics) as part of their 4-credit Graphics for Engineering Design course. Junior ME students investigated the process models and technology involved in thermoforming, injection molding and cold casting, the processes employed in the production of the plastic instruments. A graduate ME student developed finite element models and performed structural and acoustic analysis and testing of various design alternatives as part of his Master of Science in Mechanical Engineering with an IPD focus.

After additional modifications and business planning by a second Capstone Projects team in 1996, Neo Products went to market with a hit product. By 1997 Neo was getting orders worldwide and operating at its full manufacturing capacity for what it now calls the J-2 Violin, shown in Figure 2. Neil Lillien, the president and CEO of Meisel Stringed Instruments, Neo's distributor, said "The new J-2 violin has already surpassed all of our sales projections as it breaks new ground in technology and design."

[Figure 2.]

Lessons Learned by Faculty

In planning and implementing this program to foster a new learning environment, the faculty have learned as much as the students. To aid others who may wish to develop similar educational experiences for their students, we here offer a number of implementation guidelines based on our experience.

Primarily, commit resources. The IPD Program is highly resource intensive, both in faculty and industry time, but also in facilities and materials. For example simply finding and funding adequate space, tools and products for, in full implementation, 600 freshman to disassemble, reverse engineer, describe and reassemble, only one part of the freshman project course, is a major effort. As discussed in later points, the process, done well, of finding and screening capstone projects is time intensive, as is the internal and external coordination effort. IPD's development plan anticipates 1200 students and 50 projects annually by the year 2000. Program growth, however, requires support for faculty, staff, facilities, equipment, and operations. IPD's development plan, identified as a top university priority, seeks $27M in endowment and $3M for facilities and equipment. The endowment would include $6M for faculty chairs, $10.8M to support ongoing maintenance and upgrades, $4M to provide for program operations, and $9.2M for undergraduate and graduate student financial aid. Corporate and alumni contributions are crucial for enabling Lehigh to continue to take bold steps in creating an ideal environment for developing technology leaders.

Do real projects for real clients. The level of both student and faculty interest, energy and intensity increased significantly when in 1995 the Capstone Projects moved from being mostly hypothetical or faculty-invented to being 100 percent outside sponsored. Our impression is that this is largely because the increased accountability, the likelihood of seeing ideas actually implemented, and the resume building potential stimulate both students and faculty. In addition, the learning environment is richer because the design teams must squarely confront business and resource constraints, learn about and leverage existing organizational competencies, supplier systems, distribution channels and so on. Students must also manage real budgets, because we ask client companies to provide $5000 per project to cover direct research and prototyping expenses as well as course overhead. (Note that we use $5000 because it is a common threshold above which mid-level managers may have to go through more involved approval processes.) The client also serves as an additional information provider (e.g. customer lists, marketing information, materials characteristics) and sounding board for the teams. Many clients will also make available testing or other specialized equipment. Finally, there is little a faculty member can do that can stimulate interest in a project that compares to the smell of the grease, paint, and roar of the machinery during plant visits to clients.

Spend considerable effort finding and screening projects and managing clients. Related to the above, generating and screening possible projects for tractability and appropriateness also involve significant time and effort, but are indispensable. At our level of 20 projects a year this easily takes up ¼ of a faculty person's time annually. As we expand to 50 with two to four teams on each project, we anticipate hiring a full time project coordinator to serve as that liaison with potential clients. Because industry participation is so valuable for the learning environment, but the hurdle of finding and dealing with clients so time consuming, the temptation is to tackle the first projects that come along. However, some are far too ambitious for students just cutting their teeth, while others are too narrowly defined to have the disciplinary scope or to fully exercise the various students' disciplinary skills. We've found that depending on the client's needs, teams can usefully tackle projects along the entire range from initial feasibility studies of product ideas absolutely new to the market, through product line extensions, to redesigns (or redesign for manufacturability) and industrial automation. Because our teams include business and design arts students, we've had the most success in fully pushing their skills with consumer-oriented products, including, among other things, nail guns, acoustical ceiling tiles, remote controls, and furniture. An alternative for engaging more involved problems, as in the violin example above, is to have a series of projects over several years. An additional screening criteria should be the level of interest of the client, their willingness to commit time (an hour or two a week commitment is what we ask) to dealing with student inquiries, and their level of understanding of and willingness to accommodate the pedagogic goals. Continual communication and coordination along these lines with the client has proven indispensable. We would also recommend establishing as early as possible a series of standard processes for dealing with clients. Our early ad hoc, catch-client-as-catch-can process of finding projects dissipated far too much of our scarce faculty energy.

Leverage existing campus-wide resources. With growing success, the IPD program is using the unique combination of existing Lehigh resources, such as Lehigh's Small Business Development Center, Ben Franklin Technology Center, Alumni Office, Placement Office and Development Office to find industry projects and to develop funding for labs and for curriculum innovation. We should have reached out to these existing infrastructures far earlier, particularly the Development Office. As a responsive, innovative curriculum, the program sells well with recruiters and corporate and alumni donors, and the Development Office staff seems genuinely glad to have faculty willing to help them write proposals and beat the bushes. They also encouraged us to establish an active industrial advisory board. The IPD board serves as a direct feedback channel from industry and provides leadership in program planning and financial development.

Consider a Mentoring Program. An additional resource we have begun to leverage is previous students. We use a handful of top students who have already been through Capstone Projects as mentors to new project teams. For credit (as teaching apprentices), these students meet weekly with the course business faculty leader for discussions of project management, team dynamics and leadership in the ongoing context of the teams they are mentoring. Each mentor works with two or three project teams, helps them establish realistic timelines and milestones, helps translate faculty expectations, provides guidance about the kinds of tasks the teams may want to consider, gives feedback on their written and oral reports, and often answers questions students may, unfortunately, feel awkward about addressing to faculty. We learned this tip from two Lehigh faculty members who, as only 1/5 of their teaching load, direct about 100 students annually doing real-client team projects in small business management consulting. Student mentors have turned out to be surprisingly good at dealing with many of the day-to-day project team management and student coordination issues. And they learn some teaching, communication and leadership skills at the same time.

Just do it. Start small but do try it. The IPD program pilot began with no budget and eight business students joining four teams in the Mechanical Engineering Design Projects course that for decades all Lehigh ME majors had been taking. The IPD pilot in 1994 added that small willing set of business students and a single business faculty member (as a course overload). The course dynamic completely changed and there was enough interest to convince the business college dean to line-item part of a faculty slot for IPD the next year. When we added design arts students and faculty in 1996, the dynamic (and, quite significantly, the visual sex-appeal and PR potential of several key projects) changed again, and another dean and the university president were converted. By 1997, 37 faculty members across all three undergraduate colleges have participated, IPD is among the top four university development priorities, and seven figure sums have been raised in support. Our impression is that most engineering programs offer upper level design projects, many in teams, and that adding students and faculty outside of engineering (not simply having engineering students and engineering faculty do the business or the design arts) is likely widely possible. However, colleges and universities can be highly political and idiosyncratic places, so there is likely to be no substitute for local experimentation about what works for each institution. Our approach has been to move forward, learning as we go, knowing full well that there will be obstacles we will bump into (our noses have well developed calluses) and not enough resources to do what we *really* think we should be doing. We have also considerably (but slowly) raised the bar in terms of our expectations about what student teams can and should accomplish. In large part this is because students and faculty alike see what previous teams have done and aim to do better.

Our industry partners remain both enthusiastic and supportive, and as one metric of the program's success, they continue to come back for more, semester after semester. The Lehigh faculty, too, remain committed to the program. For example, the College of Business and Economics faculty have begun integrating engineering students into small business outreach project courses traditionally geared only to teams of business students, while other student teams are undertaking multi-disciplinary (e.g. business, economics, government, civil engineering) urban economic development projects with local governments and economic development agencies, and the faculty are revising the entire undergraduate curriculum based on the more multidisciplinary and integrated accreditation standards of the AACSB [25]. In the college of Engineering and Applied Sciences, MEM faculty have continued to improving the discipline-specific content of their curriculum by focusing on implementing the currently published ASME "best practices" for undergraduate engineering education [26]. In the college of Arts and Sciences, Art and Architecture faculty are working with Engineering faculty to develop the a minor in Industrial Design, and faculty in Earth and Environmental Sciences are working with faculty from three colleges at Lehigh in establishing a cross-disciplinary, undergraduate student-run, Lehigh Earth Observatory for gathering studying and making available regional environmental data for studies for outside clients. With the IPD approach, interdisciplinary faculty teams can address these objectives in a real-world context.

Clearly, our biggest supporters for the program have been our new alumni who have gone through the IPD pilots. A recent quote from Mr. Rod Kerezsi of Altec Industries, Plains PA, is typical: "Because I feel that this experience is the Mechanical Engineering Department's most valuable asset (next to some of its professors, of course), I would like to assist in any way that I can to continue its success."

Conclusion

In our opinion Lehigh's pioneering Integrated Product Development Program is unique in American higher education. It is the first and to our knowledge the only undergraduate curriculum in the nation to fully integrate the three fundamental pillars of successful product design and commercialization: design arts, engineering and business. We have developed a new paradigm for business, engineering, and design arts education that is truly interdisciplinary and intimately involves industry participation. The student teams use a wide array of available technologies, from Lehigh's access to the Internet, to extensive on-line business, economic and engineering data bases, to leading-edge industry standard CAD/CAM/CAE computing and computer animation labs, prototype development facilities, manufacturing and materials labs, and related technical staff. In the IPD approach the faculty from three colleges, industrial sponsors and upper classmen are student mentors, as well as supervisors to the student teams. The students have expressed their enthusiasm for this innovative approach as one of the key factors that makes a Lehigh education worth the expense.

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Figure 1. IPD Program Structure

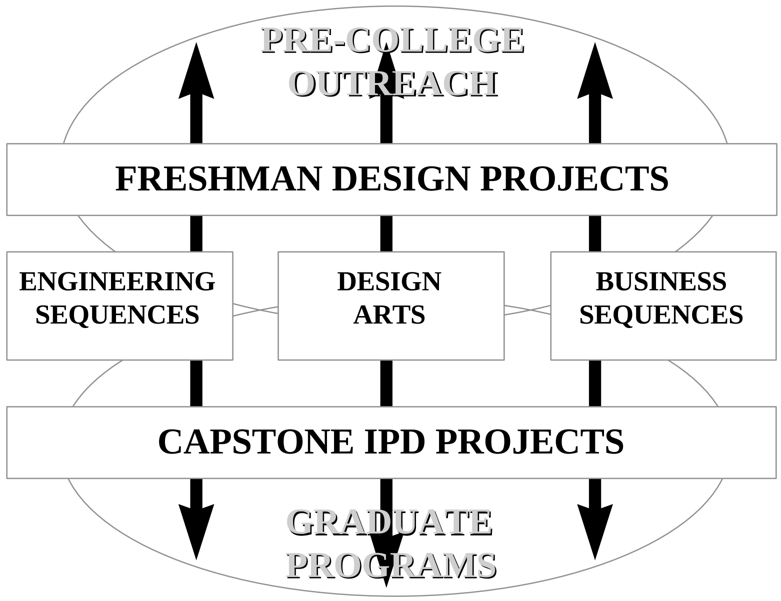

Table 1. Partial List of Sponsoring Companies

Alcoa	Competitive Technologies	Matthew Hoey Design
Apple Frankie's Enterprises	Exxon	J.E. Morgan
Armstrong	Follett	Neo Products
Arneg USA	Good Shepherd Hospital	Newton Engineering
AT&T	General Motors	Optical Radiation
B. Braun Medical	Ingersoll-Rand	Philadelphia Navy Yard
Berner International	Ingersoll-Dresser	Pratt & Whitney
Black & Decker	Johnson & Johnson	Product Premiers
Body Fit	Knoll Group	Deborah Schaffer-Brooks
Boehringer Labs	Dr. S.W. Kung	SMART Discovery Center
Briggs & Stratton	LANTA Bus Co.	Smith Industries
Century Projectors	Lehigh Valley Hospital	Solly’s Speedloaders
Chrysler	Lucent Technologies	St. Luke’s Hospital
Compatible Technologies	Lutron Electronics	Visiting Nurses Association

Table 2. Example Tasks and Deliverables
Neo Products Violin Project

Customer needs	Target specs. & constraints
Competitive benchmarking	Concept generation
Target markets	Cost & cash flow analysis
Marketing strategies	Design selection
Target pricing	Prototype & testing
Oral & poster briefings & written reports	

Figure 2. IPD/Neo Product's J2 Violin