Leveraging What Freshmen Don't Know: Product Development in an Integrated Business and Engineering Freshman Workshop

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Abstract

This paper discusses one part of our attempts at Lehigh University to put active, inquiry-based, collaborative, multidisciplinary experiences at the center of undergraduate education, starting in the freshman year. We briefly outline the goals, history, structure, and our evaluation of our Integrated Business and Engineering Freshman Workshop, a team-project-based learning course emphasizing entrepreneurial product development. The main goal of the Workshop, and the interdisciplinary curricula which it leads into, is to enable graduates to move more rapidly along their chosen career paths, graduating both competent in their functional disciplines—whether business or engineering—and better prepared for long-term success. Freshmen, by and large, come as a blank slate in terms of disciplinary biases and expectations about college "coursework." By working in teams on original entrepreneurial, multi-disciplinary product development projects from the first year, students not only become multi-functional, self-directed and team-oriented, but better understand the context of the latter courses in their curricula. The program emphasizes higher-order skill development, including: problem and task identification in ill-defined problems; decision making under uncertainty and lack of information; integrating, connecting, and reflecting on diverse areas of knowledge; and written and oral communication. We also evaluate our progress based on several related sources of qualitative and quantitative assessment information. The paper concludes by exploring the major issues and lessons learned in program implementation.

Overview of collaborative, inquiry-based education

The Lehigh Integrated Business and Engineering (IBE) Freshman Workshop discussed in this paper and the associated capstone experience offered by Lehigh's Integrated Product Development (IPD) Program (discussed in references 1-3) were designed to squarely address the major issues identified by a seemingly endless series of both academic studies and blue-ribbon panels on education. The common theme throughout is the efficacy, compared with traditional classrooms, of collaborative, active, inquiry-based, experiential learning in developing skills such as critical problem solving, problem formulation, defensible judgment, and facility in making connections among divergent bodies of knowledge and their application outside of class.

The American Association for Higher Education (AAHE) joined with the American College Personnel Association and the National Association of Student Personnel Administrators in issuing a major 1998 report [4] on student learning. Drawing from pedagogic research and practice, the joint report lays out major principles about learning and how to strengthen it. It concludes that rich learning environments require students to, among other things:

- connect ideas within and across fields of knowledge;
- integrate classroom with out of class activities;
- tackle complex problems in compelling situations (including community-based-learning);
- produce work to be shared with multiple audiences;
- be active directly in the discovery of knowledge;
- collaborate with others in study and shared research;
- demonstrate learning through active problem solving, applying concepts to practical situations; and
- participate as active citizens in the broader community.

The AAHE is far from alone in this chorus. In what has become known as the Boyer Commission report [5] of 1998, the Carnegie Foundation for the Advancement of Teaching was strongly critical of the nation's 125 research universities for the deep barriers between undergraduate teaching and the inquiry-based activities of the faculty. Most research universities, they conclude, give undergraduates "too little that will be of real value beyond a credential that will help them get their first jobs." The report calls for "a complete transformation in the nature of the education offered." Into what? Rich environments for inquiry-based, collaborative, interdisciplinary education: "The ecology of the university depends on a deep and abiding understanding that inquiry, investigation, and discovery are the heart of the enterprise…. Everyone at a university should be a discoverer, a learner. That shared mission binds together all that happens on a campus. The teaching responsibility of the university is to make all its students participants in the mission."

Business leaders also believe American universities fail to deliver. A 1995 study [6] 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." 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 (including leadership, communication, integration of knowledge across the curriculum, a multidisciplinary perspective, teamwork, active learning and collaboration.)[7]

In addition to these general calls for reform in undergraduate programs, educators have stressed similar curricular deficiencies in targeted fields. For example in engineering, 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.[8] 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,[9-16] including from the National Research Council[9] and National Science Foundation.[16] So too, the Accounting Education Change Commission[17] calls for students who are active rather than passive participants in the learning process and an emphasis on unstructured problem solving and incomplete or unstructured data. In business and management there has been a parallel flood with remarkably similar emphases.[18-24] Indeed, the literature on the value of multidisciplinary collaborative project-based curricula date back at least 30 years.[25]

Though change in the American university system has been slow, significant steps are being taken. Perhaps most importantly, national professional organizations and academic accrediting bodies such ABET (e.g., ABET 2000)[26] in engineering and AACSB[27] in business now actively encourage more integrated, team-based and cross-disciplinary curricula. Similarly, the American Accounting Association[17] suggests that students be "active participants in the learning process, not passive recipients of information… identify and solve unstructured problems that require use of multiple information sources", work in groups and emphasize learning by doing. In part because of recent emphasis on integrative design education by ASME,[28] active, cross-disciplinary design education is increasingly well ensconced, particularly across disciplines in engineering schools. Collaborative team-based product design courses of various flavors are also offered at dozens of universities.[29-32] Here at Lehigh, the disciplinary integration in design is particularly diverse: the Integrated Product Development program combines students and faculty from engineering, business and design arts in product development teams.[1-3]

Not only are such active, interdisciplinary, experiential, collaborative offerings increasingly popular, educational research evidence[33-34] 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[33] of more than 600 studies over the past 90 years put it:

> "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.… 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."

The Integrated Business and Engineering Program at Lehigh University

For the past three years, Lehigh University has offered an honors BS program in Integrated Business and Engineering (IBE), a joint degree offered between Lehigh's College of Business and Economics and our Rossin College of Engineering and Applied Science. The IBE curriculum, supported in part by Lehigh's Integrated Product Development (IPD) Program, features a multidisciplinary freshman projects workshop course, described in this paper, a capstone technology entrepreneurship experience, as well as special seminars or workshops each semester. IBE students can major in any of Lehigh's business fields or in electrical engineering, civil engineering, computer technology, environmental engineering, industrial engineering, materials science and engineering, mechanical engineering, or structural engineering, while taking a variety of courses in business, engineering and arts. This program has language proficiency and summer internship requirements, and study abroad opportunities.

As background, Lehigh is a Carnegie Research II institution with approximately 4500 undergraduates, 1900 graduate students and 400 full-time faculty. Ranked among the top 40 national research institutions by US News, Lehigh is also rated in the "Most Competitive" category by both Barron's and Peterson's college guides. The first IBE class entering in 2000 had 33 students selected from over 600 applicants with a combined average SAT of over 1400. The second class in 2001 had 55 students with an average SAT of 1450. The third class in 2002 has 43 students, with a similar academic profile. Now approaching steady state, the program is expected to continue to enroll about 50 students per year. Lehigh is located in Bethlehem Pennsylvania in eastern Pennsylvania's Lehigh Valley, about 80 miles west of New York City and 50 miles north-northwest of Philadelphia, i.e. squarely amid the principal NYC-NJ-SEastern PA industrial and high-technology region. This enables the industry expert participation and class field trips.

In support of the IBE and IPD programs, Lehigh University has a brand new, fully staffed and equipped 17,000 sq. ft. student entrepreneurial design and prototyping workshop, multiple sites with high-end industry-standard CAD labs (running, inter alia, Unigraphics, IDEAS, Alias/Wavefront, and graphic design and other modeling software), and student team work space. Lehigh also has a multi-million volume library and computer based tools for simulations and decision making for engineering and business applications, and state of the art computer and information systems that supports patent searches, web browser, data base access, interactive computer graphics, large screen projection for presentations, video and computer animation capability. The programs are also supported by a supervised student shop, a small-scale rapid prototyping machine, a machine shop staffed by three full-time machinists, and a full-time electronics technician. Lehigh's Mechatronics labs support projects with embedded microcomputers, and our world-ranked Materials Science Department makes research equipment and faculty and technician assistance available to student teams.

IBE Freshman Workshop course objectives

The principle objective of the IBE Freshman Workshop course is to introduce how businesses, engineering and design activities create value. The focus is on innovation, technical entrepreneurship and the business value chain. Student teams design new products and develop business plans and start-up funding proposals, and take apart existing products and the competing companies that make them. The three authors, one each from business, engineering and design arts, have been the primary faculty responsible for the Workshop's design and implementation. We team-teach every element of the course, and all attend each activity. As a result, the course is truly multidisciplinary and integrated in content and design.

Our goals are that students develop skills in and basic functional ability to undertake: analysis of customer needs, competitive strategy and marketing mix; financial modeling; organization of the supply chain; virtual (computer) modeling; engineering drawing; development of technical specifications; testing and measurement; brainstorming; new concept generation, screening and selection; and overall business planning. We demonstrate the need for modeling and simulation for both business and engineering applications through regular questioning of technical and economic feasibility. We introduce analytic tools and modeling and simulation techniques and the students get hands-on experience with enabling technology by then using state-of the art industry standard tools.

In structuring the course around multidisciplinary team projects in the freshman year, we also try to indoctrinate the students with what are sometimes considered the softer skills. Principal among them: respect for other disciplines and teaming as a natural approach to problem solving. We schedule this indoctrination early in their academic careers, before student perceptions of chalk-talk-problemsets-test teaching methods or of disciplinary silos become strong. We also try to get the student problem-solving to have customer focus from the start. We emphasize field research, customer interviews, market testing and benchmarking. So too, through a series of deliverables, we work with students to improve their written, oral and graphical communication skills, and also to become better decision makers when facing unstructured, uncertain and ill-defined problems. Finally, freshman cannot be expected to do all the activities we ask of them effectively at a professional level. By this trial by fire, the students should better understand the value and relevance of courses later in their curricula and become more willing to admit ignorance and seek help.

Teaching approach

Our approach emphasizes active, participatory and team-based inquiry. We have quite high expectations of students in this course, so to the extent possible we minimize lecturing and maximize hands-on or, better yet, brains-on activities. This means that rather than lecturing about and repeating what students can independently read in the textbook, we simply expect that they have read it and are prepared during class and team meetings to participate in thorough, joint exploration of the topics at hand. What we have in mind is closer to the style of upper-level seminars with faculty mentoring than to the generic lecture/homework/exam introductory course for freshman.

The mechanism we use to create this seminar-like environment among 40-50 students (in ~10 teams) revolves around the weekly Friday three-hour workshop session followed by a Tuesday 75-minute "crit" session. By crit, we mean an open discussion aimed at constructively critiquing the in-process work presented each week by two or more randomly chosen teams. We also expect each team to meet independently at least once per week.

We borrowed the concept of the crit sessions from our Art and Design colleagues, who use crit sessions to comment on student artwork. We also conceptualize our role like a Music teacher or a conductor, who might constructively critique the ever-improving playing of a music pupil during lessons or rehearsals. The musicians practice outside of the contact time with the instructors, display their work in very rough, in-process form, get suggestions for improvements, and then revise accordingly. We believe that business, engineering and design decision-making, like music and art, have large doses not only of technique, but also of creativity, intuition and art.

So, a typical week of the IBE Freshman Workshop goes like this:

1. We hand out a workshop assignment on Friday, generally with illustrative examples, and provide a brief (15-20 min) overview of the techniques and topic at hand;
2. The students begin work during that Friday workshop, with the 3 faculty and 2 TAs wandering from team to team addressing questions, commenting on progress, and generally mentoring;
3. Teams typically assign individuals to additional tasks to be done outside the workshop sessions such as field research or revisiting the computer or shop facilities to continue work;
4. Teams nearly uniformly meet again independently before the Tuesday classtime to come prepared to the crit sessions to present to the entire class their in-process ideas;
5. During the crit they get (or they watch other teams get) constructive critical feedback from the faculty and other students on those ideas;
6. Based on this input they revise and improve their ideas over the next several days;
7. They then submit the completed assignment at the start of the next Friday workshop session;
8. These we grade and return by the next session, at the start of which we generally make oral comments on strengths and weaknesses of the just-returned assignments.

By not lecturing on every topic, detail and technique, we, rather, focus our contact time on critiquing whatever elements are weakest in their independent work. We can ignore material they show they have mastered on their own. We find that because they have to defend their ideas in front of 40 or more of their peers, they have significantly higher incentives for independently tackling the material than in more typical classes. In order for them to give credible crit presentations and responses, they need to have digested the material from the work. As a result we have had very little problem with these students not independently reading and struggling to understand the textbook material.

To focus the course discussion among the students, and to make organization and grading relatively manageable, we narrow the range of possible products to one sector each year. Teams invented sporting goods in 2003, toys in 2002 and hand power tools in 2001. In retrospect this last was a poor choice. Students lacked the real energy and interest they showed the next year in the toy projects.

Textbook, lab notebook and project budget

Our textbook is Ulrich & Eppinger, *Product Design & Development*, 2nd edition, Irwin-McGraw Hill, 2000. We also require students to keep bound laboratory notebooks. Like industry lab notebooks, the project notebook is a record for all planning (including plans not carried out), all analytical work, sketches, comments or questions that pop up during conversations, all records of customer interviews, competitive analysis, experimental work or financial estimates, references to all sources of information used, and all other significant thinking about the project and directly related subjects. We encourage students to get in the habit of recording all their thinking ("noodling and doodling" we call it) regardless of the apparent importance of the information. Because teams are inventing, we also strongly signal that these notebooks are more than simply an academic exercise. Students know the notebooks are intellectual property evidence if their ideas turn out to be marketable and/or patentable.

In addition, we recommend each team organize a 3-ring loose-leaf binder as a library of team documents and notes. Additional requirements include each team acquiring a potential competitor's product to take apart and reverse engineer. Each team has a budget of up to $200 to cover expenses. This funding comes as a line item from the regular IBE program budget.

Course deliverables

Grades reflect a combination of individual and team performance on a series of deliverables. These include homework (20%), laboratory notebooks (10%), first draft (10%), second draft (10%) and final draft (20 %) team reports, a team oral presentation (10%) and team poster (10%) and crit discussion participation (10%). We also ask each student to evaluate their teammates' contributions to the team outcome. We adjust the team-based portion of the grade up or down based on our and the peers' evaluations of an individual's contributions and effort.

The most important deliverable required of each team is the final written team report. However, this is not a report in the traditional sense. Instead, to create a higher level of expectation and motivation, we ask that the final written output be a grant proposal to get start up funding for a new product business. We aim each year to send one or more of the best to a national competition for student technical entrepreneurs run by the National Collegiate Inventors and Innovators Alliance (NCIIA), funded by the Lemelson Foundation. Student and faculty teams from Lehigh's IPD program have won at least one of these awards each of the last seven years, so the students know they have a realistic chance of winning up to $20,000 to fund further development of their entrepreneurial ideas. In the event the teams win a grant, the project then becomes their capstone design experience later in the curriculum.

Each week's homework assignment, then, is designed to contribute content or background context for those proposals. Successful proposals generally include an overview of the industry and target market, current competition, customer needs, technical benchmarks, a description of how the new product idea satisfies those needs better than existing competitors, target specifications and target prices, market entry strategies, channels and promotional ideas, financial projections, materials selection, manufacturing plan and bill of materials (see example BOM and cash flow analysis in Appendix II), testing and development plan, a work plan and timeline, and a grant budget. Teams also prepare CAD models (see examples, Appendix I) and do preliminary prototyping and testing. As background context, we generally start the course asking the students to research the overall industry, major competitors (see Appendix III), and to reverse engineer a competitive product in the same niche as their idea (see Appendix IV). The course timeline in Table 1 shows the sequence of these topics throughout the spring semester 2003.

This is a tall order for a group of freshman in one semester: to get up to speed on an industry and the companies and product areas in it; to understand how the supply and distribution system works; and then to develop a nationally competitive five-figure grant proposal containing substantive, succinct professional discussion of all these issues. Nevertheless, we were comfortable enough with four of the ten teams during the spring 2002 course to submit their proposals. We had actually hoped only for at least one, so the class on the whole exceeded our already high expectations. In February 2003 we learned that two of the four actually won grants of $13,500 and $13,600, respectively.

The semester ends with team oral presentations, during which teams present their business plans and product concepts to outside industry professionals that we invite to campus. Our experience has been that, because the freshmen are nervous about their lack of experience, the students put far more effort into preparing for these briefings than they do for other class presentations with no outsiders involved. We have an hour set aside the week beforehand for each team to go through a dry-run. One or more of the faculty help them structure and polish their first cut. The last two years, the outside experts have uniformly complimented the level of professionalism of the projects, while at the same time giving helpful critical suggestions to the teams about how they might improve their ideas.

These oral briefings are followed by a public poster session, where all the teams present a poster (designed with the help of the Art faculty, using industry standard graphic design software) with their product concepts, key business and technical feasibility analysis, integrated with a consistent graphic look and brand image. Figure 1 shows two example brand logos from 2001 and 2002 and two example posters from spring 2002 are in Appendix V. We then mount, frame and hang these posters for posterity around the business college and engineering college buildings. Our intent is to increase the quality of the hanging posters over time, adding new ones each year, leaving only the best as examples for current students and as publicity for alumni and prospective students to see on their tours around campus.

Table 1. IBE Freshman Workshop calendar, spring 2003

A brief outline of topics and activities through the semester and key due dates follows. Note that Fridays are generally working lab sessions, and Tuesdays are the "crits."

Date	Activity & Deliverables
T 1/14	Course Overview; Introduction to Product Development; IDEO Video
F 1/17	Crit: Each of 10 teams presents their Logo Design; Brainstorming Methods Discussion & Brainstorming Lab
T 1/21	Crit: Two or more randomly called teams present their Sporting Goods Industry Analysis
F 1/24	Each of 10 teams presents their preliminary Sporting Goods Product Ideas; Discuss Target Markets & Product Differentiation
T 1/28	Crit: Two or more randomly called teams present their Competitve Analysis; Conceptual Maps & Preliminary Marketing Mix
F 1/31	Customer Needs Assessment & Product Functions Lab: Teams aquire, use and evaluate competitive products; Discussion and first cut of Translating Customer Needs Into Technical Specifications
T 2/4	Crit: Two or more randomly called teams present their Needs Metrics Matrices
F 2/7	Reverse Engineering Lab based on competitive products; Engineering Measurement; Engineering Sketches of Competitive Products; Bill of Materials; Functional Decomposition
T 2/11	Crit: Two or more randomly called teams present their Functional Diagrams
F 2/14	Materials, Manufacturing Processes & Costs; Process Video; Using competitive products and a collection of example materials and manufactured parts and artifacts, teams try to estimate what the competitive products are made from, how, and estimate costs of manufacturing.
T 2/18	Crit: Manufacturing Process Ideas & Competitive Bill of Materials
F 2/21	Concept Generation Brainstorming, Functional Combination and Selection Lab; Customer Surveys Revision
T 2/25	Crit: Concept Screening & Scoring Matrices; Revised Customer Surveys
F 2/28	Industry/Plant Visit Field Trip **First Draft NCIIA Grant Proposal Due on Bus**
T 3/4	Crit: Competitive Benchmarking Maps & Competitive Strategy
F 3/7	Virtual Modeling Intro Lab; Intro to Financial Models Lab; Workshop Safety Video
T 3/18	Crit: Financial Modeling & Sensitivity Analysis; Prototyping Plan
F 3/21	Virtual & Physical Prototyping Labs;
T 3/25	Crit: Business Plan Elements
F 3/28	Business Planning Conferences with Industry Professionals, with focus on Market Niche, Mix & Competitive Strategy
T 4/1	Crit: Target Markets & Target Specifications
F 4/4	Engineering & Market Testing; Advertising & Brand Image; Introduction to Industry Standard Graphic Design Software
T 4/8	Crit: Poster Concepts & Brand Images
F 4/11	Graphic Design and Image; Poster Workshop **Second Draft NCIIA Grant Proposal Due in Class**
T 4/15	Crit: Engineering and Market Testing Plans
F 4/18	Dry Run Oral Briefings
T 4/22	Wrap-Up; Finish Work Session
F 4/25	**1-4PM: Final Oral Briefings for Outside Industry Professionals; & 4:15 –7 PM Poster Session & Celebratory Banquet with Families**
T 4/29	**Final Draft NCIIA Grant Proposals Due**

Figure 1: Two example logos, IBE Freshman Workshop, spring 2001 and 2002

Evaluation and lessons learned

We now turn to lessons learned, in the spirit of continuous improvement. We hope these may be helpful implementation guidelines for others exploring new approaches to undergraduate business, engineering and design education.

First, the students themselves tell us they think they are learning: On a scale of 1-5, in 55 course evaluations during spring 2002, the mean student responses were

- 4.5/5 to the statement: “will be a better engineer or business decision maker;”
- 4.4/5: “have a clearer understanding of engineering & business practices in a competitive marketplace context;”
- 4.2/5: “believe I could develop a simple business plan;”
- 4.3/5: “am better able to identify and meet customer needs in business and engineering problem solving;”
- 4.3/5: “The project had a successful outcome;”
- 4.1/5: “Overall I learned a great deal in this class;”
- 4.1/5: “The overall instruction in this class was effective.”

Two areas we need to significantly improve are the laboratory notebooks, where the students rated their usefulness at an unacceptably low 2.6/5, and the engineering sketching activities which students rated as 3.4/5.0. For the notebooks, we believe we need to give more up front guidance and more regular feedback on how to use them, and to show examples of good ones. We did little of this in prior years. The sketching, we interpret, on the other hand, as being in large part due to the amazing capabilities of the computer design tools available. Sketching skills are far harder to master, and the perceived value is lower, despite our belief that they are in fact quite useful during brainstorming, team communication, and conceptualization processes. We continue to think, but have yet to have much insight, into how to improve this perception among the students.

In terms of lessons learned, we offer the following:

Do Real Projects with a Real Outlet and Feedback from Industry Experts.
The level of both student and faculty interest, energy and intensity is significantly greater in projects with the external pressure of the national NCIIA competition or (from our 8 year

experience with the IPD program) external clients when compared to mostly hypothetical or faculty-invented projects. 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 teams must squarely confront economic, technical and resource constraints, and learn about and leverage existing real markets, products, and companies. The outside expert evaluations in both the NCIIA review process and also in the on-campus oral and poster sessions serve as additional feedback for the teams. Finally, there is little a faculty member can do that can stimulate interest in a project—and the personal internal desire to actively inquire about things unknown—that compares to the possibility of real start up money in a national competition.

However, up front we needed to put some reasonable constraints on which product ideas the students pursue. A completely open process, across many sectors with widely divergent customer bases, technology bases, distribution and marketing channels, would not lend itself to the depth of discussion or sharing of ideas that we want to encourage. That said, in our first year we were far too narrow with the freshman, underestimating their capabilities. We chose to have them simply try to reverse engineer and then improve existing products from two competing manufacturers of hand-held power tools, Black & Decker and Ingersoll Rand. We thought that the discussion of the industry, markets and competitive strategies, as well as the technologies involved, would be better if every team was essentially tackling the same narrow area: power hand tools. We also chose it because of what we thought was a nice balance between consumer orientation and reasonably but not too complex electro-mechanical products. The hand-tool sector was somewhat boring for 18 year olds, but the larger incentive problem was that the product ideas were not theirs. Because the products already existed, students were more intimidated than we anticipated by the challenge of improving them. A typical comment was "how can we improve on Black & Decker?" Teams ended up recommending new triggers, slight changes in shape and so forth. The resulting level of creativity and entrepreneurial energy during that first year was far lower than we'd hoped. Our experience the second year was far, far better. Students invented their own toy ideas, reverse engineered existing competitors to begin with, then designed and did business planning for their own ideas. Because the ideas were original, we could then add the dimension of submission to the national competition.

Even so, in the second year, in retrospect, one (of 10) project idea was significantly too complex to be reasonable for a one semester freshman experience, and two were too simple technically to satisfy our hope that the students struggle with technical problem solving. As a result, we have become more willing this third year to say no to ideas as they evolve during the first two weeks of the course. The projects must be technically tractable and have fairly clear consumer market focus, yet at the same time be challenging enough to significantly stretch the capabilities both technically and creatively of these honors undergraduate students.

As we indicated above, we have been pleasantly surprised at the high fraction of teams that have gone far beyond our full expectations. As a result, we have considerably 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.

Provide Multiple Opportunities for Students to Present and Reflect on Their Ideas.
We believe that as faculty we can provide a much richer mentoring experience for the students if we engage them on multiple levels in exploring and reflecting on their own ideas and progress. This elevates the learning experience well beyond what students could get on their own through, for example, summer internships. While these latter are very often valuable, they do not leverage the unique inquiry-rich features of the research university, nor do they necessarily exercise and integrate skills learned in earlier curriculum. Faculty and peer mentoring and feedback can.

We have several approaches to encourage students to present and reflect on their ideas. The most informal are the required weekly meetings among each student team. With three or four peers, from week to week, they need to decide what key issues the team faces and collectively decide how to tackle them. Though we do not monitor these meetings, if the literature on collaborative education is right, this immediate peer feedback can be a valuable learning experience.

The next, only slightly more formal level, is the weekly crits with the faculty. We try to focus these meetings and our feedback on key issues by having each team come prepared with a summary of their in-progress thoughts from the week and plans for the near future. This makes them collectively reflect, ahead of time, on where they have been and where they need to go. Though we crit for only about 75 minutes per week, with two or three teams, we find that we are able to provide far more, more frequently and more targeted feedback to each student than we would in a traditional classroom. We have pushed, for example, a very capable team to develop dynamic finite element simulation models based on deepening their initial AUTOCAD models, and explored sources of materials, materials limitations and failure-mode modeling problems in testing their original design concepts. At the other end with other students, we re-acquainted them with and exercised notions of, for example, medians and basic spreadsheet skills. At either end the students were challenged to and wanted to move beyond their current capacities in order to address real market-driven questions. At either end, there was a sense of accomplishment and reward well beyond grades for the effort.

Another level involves quasi-formal oral briefings that each team gives to the whole class and outside industry experts. This does at least three things. First, the focusing lens of a public presentation in front of their peers requires each team to organize and distill their thoughts and be prepared to defend them. Second, the process of and feedback from preparing, giving, and watching others give presentations, we think, exercises and clearly improves communication skills. The quality and professionalism of the talks is demonstrably far higher at the end of the term than the first few crit sessions or even the one-week early dry-run.

Third, students see the business and technical issues that each of the other teams faces. This significantly broadens the context for them, illuminating the breadth and diversity of the types of problems professionals face. Admittedly this approach cannot cover the full scope of the fields, as a series of textbooks might. However, we believe the fairly ad hoc collection of the topics students come up with on their own is more than made up for in the depth of student interest and understanding--and presumably superior long term retention. The presentations and class discussions personalize the issues like no textbook can because students share with peers going through the same process of inquiry and discovery. They share the struggle over the types of questions their peer teams are asking, the methodologies and background materials brought to bear on these other design and business planning problems, and as a class can collectively brainstorm and reflect on each team's approach while in progress.

One more formal level of presentation and reflection entails the draft grant proposals and lab notebooks. The value of the process of completing and getting feedback on written report drafts will be familiar to most reading this. The only point we might add here is that the weekly written team (rather than individual) assignments and several stages of team drafting requires early-stage collective reflection and decision making on problem definition and planning. The laboratory notebooks may not be as familiar. Individual students must organize their raw data, interview notes, background papers and weekly meeting notes. In the process we hope they develop habits of documentation potentially useful later in their professional lives, while at the same time regularly distilling the raw materials and reflecting on what materials might be relevant in terms of future intellectual property and other business uses.

Finally, the most formal level involves the final oral presentation, public poster session, and written grant proposals to the NCIIA. Here the anxiety factor has its strongest incentive, and we've found it a significant magnitude greater than for traditional final in-class presentations. The payoff is far higher as well, in the form of the students' often-palpable internal rewards for presentations well done, requests for tens of thousands of dollars seriously considered and kudos from professionals. Grading schemes simply cannot match these incentive and reward effects.

While it is possible that our experience is unusual, it does seem to match closely the pedagogic recommendations of the literature cited above. Lectures, textbooks, problem sets and tests have fundamental utility in curricula, but should not constitute the entirety.

Resource Needs Are Manageable.

When we began planning our pilot course, we anticipated higher resource needs than have emerged. We thought the process of mentoring the teams would consume more than teaching traditional lectures, when in practice it is no more than 20 hours for each of us per term. We actually prepare less than we would for a normal class, because we cannot fully anticipate what the students might come up with for us to critique. Essentially, we rely on years of experience working with student teams, rather than on preparing lecture notes. Between three of us, from different disciplinary backgrounds, there is always more than enough to talk about during class. One might question using three faculty to teach one class, but with 45-55 students expected in the class each year, it is as if we were each teaching 15-20 students in individual sections, which is slightly-but-not unusually low by Lehigh freshman seminar class-size norms (usually 20-25).

We do have the luxury of 1) Lehigh's extensive laboratory, computer and library resources, 2) two TAs for grading purposes and for helping set up the workshop space, as well as 3) $200 per team for prototyping expenses and for purchasing competitive products to reverse engineer. Presumably these last minor expenses could be left to the students. But regarding the first, it would be hard for us to imagine this course in a college without significant engineering facilities, or in one without a business program.

Moreover, there are benefits to us as well as the time costs. We are learning along side our students as they tackle problems that we have never struggled with ourselves, sometimes stimulating thinking about our research agendas. We also get more psychic reward in teaching this way since the students are considerably more engaged, and their time and our time might actually have real market value. And for a bit of fun, the projects sometimes have resulted in the students' and our names in the media. We conclude, then, that the resource costs are equivalent or lower than traditional courses while the benefits are higher.

Consider Team Teaching

Each instructor has a different background and expertise, and we believe that diversity strengthens our collective mentoring. However, there have been at least two unexpected additional areas of benefit. First, the process of providing feedback can be tiring, and with three of us in the room, when there is some brain-downtime by one of us, the others can fill in. There are also regular occasions in which we disagree with each other, which in retrospect we think gives the students more realistic understanding of how professionals operate in making decisions when there is no clear right answer. The students become much more comfortable asking questions and making informed, but not completely informed, judgment calls.

Consider a Mentoring Program Using Former Students as Advisors.

An additional resource we have not yet begun to leverage is previous students. Should the program grow beyond our capacity to fully advise 10 teams, it might begin to make sense to use a handful of top students who have already completed the junior/senior capstone experience as mentors to new freshman project teams. These students would meet weekly with the course faculty to discuss project management, resources, team dynamics and leadership in the ongoing context of the teams they are mentoring. Each mentor would work with two or three project teams. They could help them establish realistic timelines and milestones, help translate faculty expectations, provide guidance about tasks the teams may want to consider, give feedback on their written and oral reports, and answer 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 75-100 students annually doing real-client team projects in small business management consulting in the Lehigh Management Assistance Counseling program (LUMAC). This was also adopted successfully in IPD, discussed above, involving about 200 students annually on 30-35 integrated product design teams. Student mentors in both LUMAC and IPD have turned out to be surprisingly good at dealing with many of the day-to-day project team management and student coordination issues. And the mentors learn some teaching, communication and leadership skills at the same time.

Just do it.

Freshmen are in many ways open slates. Knowing they don't know much, they can be more willing than our seniors to ask good questions, seek out help, ignore disciplinary silos, and participate actively in class discussions with their equally unbound peers. We completely underestimated their potential our first year. The relative (by university standards) speed of implementation and ramp up to steady-state resources was fundamentally helped by the existing campus experience with similar inquiry-based programs in management consulting (LUMAC), product design (IPD) and environmental research (Lehigh Earth Observatory). 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.

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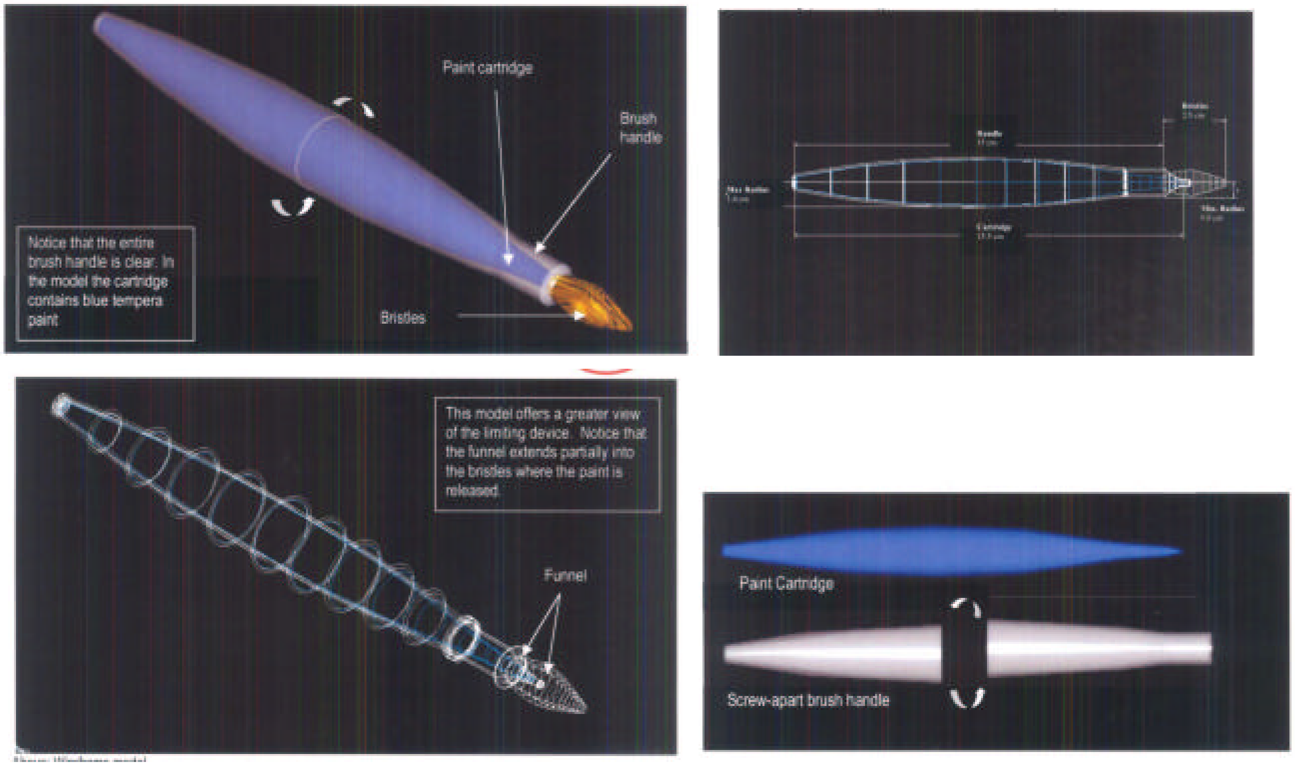
Appendix I: Example CAD Models, Freshman IBE Workshop, 2002.

New Design Painting's No-Dip Paintstick, Various Views.



SimThrow, Softball Pitch Simulator

Appendix II: Example Bill of Materials & Cash Flow Financial Analysis, IBE Freshman Workshop 2002

Bill of Materials

Part of Product	*Component*	*Quantity*	*Material*	*Size*	*Source*	*High Cost*	*Low Cost*
Apparatus	Plastic tube, 4'	1	Clear polyurethane	4' long, inner radius 3"., thickness 0.25"	TEEL Plastics	$2.40	$2.40
	Plastic tubing, 8"	1	Clear polyurethane	8" long, inner radius 3", thickness 0.25"	TEEL Plastics	$0.50	$0.50
	Plastic couplings	2	White, ABS Plastic	4" long, inner radius 3.3", thickness 0.3"	TEEL Plastics	$3.00	$1.75
	Knobs with metal screws	8	-	1/2" screws	ACE Hardware	$0.05	$0.02
Ball Feeder	Plastic hopper	4	ABS plastic	Cutoff square pyramid, base 12", height 14", 1/8" thick	TEEL Plastics	$0.15	$0.10
	Support legs	2	6061 Aluminum	2.5' long, 1" diameter	Bethlehem Steel	$0.20	$0.10
	Support tray with legs	1	AISI 1020 Steel	-	Bethlehem Steel	$0.50	$0.40
	Knobs with metal screws	4	-	1/2" screws	ACE Hardware	$0.04	$0.02
Firing mechanism	Metal step cap	1	6061 Aluminum	Circle, diam 3.5"	Bethlehem Steel	$0.20	$0.10
	Foot pedal casing	1	ABS plastic	-	TEEL Plastics	$0.04	$0.02
	Solenoid encased in cable	1	-	42' long	-	$5.00	$1.00
	Spring	1	-	2" long	ACE Hardware	$0.02	$0.01
	Firing lever	1	AISI 1020 Steel	2" long	Bethlehem Steel	$0.03	$0.02
	Cost of Materials					**$12.08**	$6.41
	Overhead/Manufacturing Costs/Labor @ 45% of materials					$5.44	$2.88
	Total Cost					$17.52	$9.29

Base Case Financial Model

$ values in thousands	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
DEVELOPMENT COST	($20.0)							
RAMP-UP COST	($90.0)	($10.0)						
LEASING PRODUCTION SPACE		($20.0)	($20.0)	($20.0)	($20.0)	($20.0)	($20.0)	($20.0)
MARKETING & SUPPORT COST			($5.0)	($5.0)	($5.0)	($5.0)	($5.0)	($5.0)
PRODUCTION COST			($1.8)	($5.3)	($14.9)	($19.3)	($17.5)	($17.5)
Quantity Produced			100	300	850	1100	1000	1000
Unit production costs			($0.018)	($0.018)	($0.018)	($0.018)	($0.018)	($0.018)
SALES REVENUE			$40.0	$120.0	$340.0	$440.0	$425.0	$425.0
Quantity Sold			100	300	850	1100	1000	1000
Price before retail mark-up			$0.400	$0.400	$0.400	$0.400	$0.425	$0.425
PERIOD CASH FLOW	($110.0)	($30.0)	$13.3	$89.7	$300.1	$395.7	$382.5	$382.5
NPV contribution each year	($110.0)	($26.1)	$10.0	$59.0	$171.6	$196.7	$165.4	$143.8
Cost of Capital	15.0%							

NPV of *SimThrow* **$610.4**

Total revenues **$1,790.0**
Total initial investment **($140.0)**
ROI of SimThrow (using NPV) **436.02%**

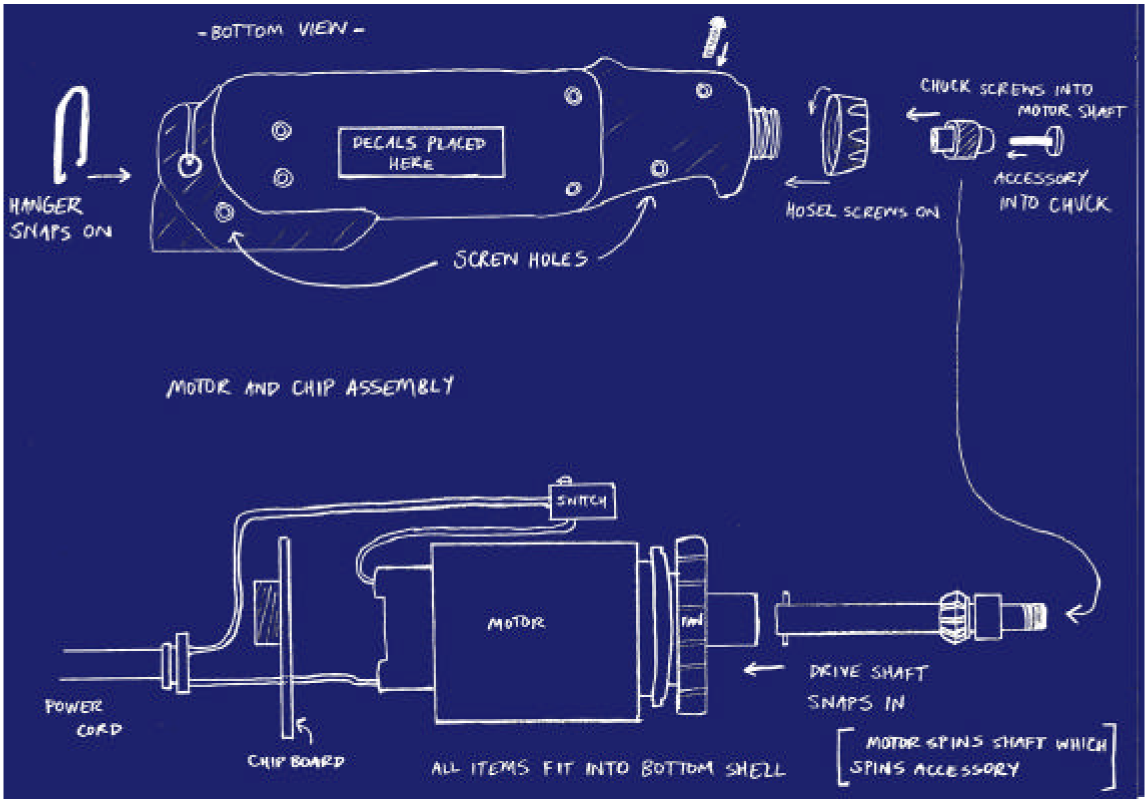
Appendix III: Example PowerPoint Slide from Final Oral Briefing, IBE Freshman Workshop Spring 2001

COMPETITIVE BENCHMARK DATA




Manufacturer	***Dremel***	***Black & Decker***	***Black & Decker***	***Dremel***
Type	*Rotary Tool - MultiPro*	*Rotary Tool - Wizard*	*Rotary Tool - RTX*	*Rotary Tool - MultiPro*
Model	7700	VP940K	RTX-1	275
Size				
Speed	2 Speed	2 Speed	Variable	1 Speed
Motor	7.2V	3.6V	2.0 Amp	1.2 Amp
OPM/RPM	12,000 - 15000	13,000 - 18,000	8,000 - 30,000	15,000
Power	7.2V Battery w/ 3 hr Charger	3.6V VersaPak w/ 6 hr Charger	Corded	Corded
Accessories	50	63	55 assorted	5 assorted
Special Features	MultiPro Tool Kit	Small, maneuverable unit	Variety of Accessories and Flexible Shaft	Base-line Dremel Model
Price	$39.97	$47.67	$59.88	$34.97
Weight	3.36 lbs	1.2 lbs	1.3 lbs	1.81 lbs

Appendix IV: Example Reverse Engineering System Sketch, IBE Freshman Workshop 2001



Appendix V: Example IBE Freshman Workshop Posters, 2002