

AC 2007-1633: ENTREPRENEURSHIP VIA MULTIDISCIPLINARY PRODUCT DEVELOPMENT

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Dr. James V. Dupree, Ph.D. is the creator and Director of the Entrepreneurship Programs at Grove City College. His responsibilities included creating the program, developing the B.S. in Entrepreneurship, establishing the fifteen-member Entrepreneurship Advisory Council, initiating the annual business plan competition, building external strategic alliances with local and regional business, and facilitating cross-disciplinary teaching and cooperation with college programs in engineering, sciences, and liberal arts.

Dupree is a Professor of Entrepreneurship and chair of the Department of Entrepreneurship at Grove City College. He teaches core courses in both Business and Entrepreneurship. Dupree established the Entrepreneurship Advisory Council, consisting of fifteen executive-level Entrepreneurs who come to campus twice a year to advise the program. Furthermore, Dupree in cooperation with Development and the Entrepreneurship program staff won and administrate a 3-year \$150,000 grant from the Coleman Foundation.

In addition to his academic accomplishments, Dupree has over 10 years of corporate and small business experience in sales, sales training, and program development prior to coming to Grove City College in 1990. He continues to have an active hand in small business start-ups and social enterprise in the region. Dupree served as a field artillery officer in Viet Nam, receiving a bronze star for valor and has been actively involved in Christian interdenominational ministry and served as a small country church pastor.

At the University of Arizona, Dupree received a BA in International Relations. He earned his Masters of Divinity in Pastoral Studies at Denver Seminary, his Master of Arts in Communication at Northern Illinois University, his Doctorate in Communication at Pennsylvania State University, and certifications in International Business and International Marketing at the University of South Carolina.

Entrepreneurship via Multidisciplinary Product Development

Introduction

Engineering and computer-science students in senior-level design courses often have strong entrepreneurial interests. These students want to develop their design projects into commercial products. One venue for commercializing design at our institution, Grove City College (GCC), is the annual on-campus business plan competition. For the last four years, business and entrepreneurship students often partner in writing a business plan. Students received written feedback from practicing technology entrepreneurs on their plans. That students report the competition as a favorable experience fostered the idea for what we called the *High Tech Venture Start-up* course.

The business plan competition, however, lacked several essential elements to be a fully integrated and maximally valuable educational experience. As important as business-plan writing may be, we believe that it is a limited view of entrepreneurship, particularly for our engineering and computer science students¹. The competition focuses attention on financial and marketing issues *after* the product has been designed. A more realistic perspective, and one that appears to be of greater interest to the engineering students, is to design a product from scratch while working under marketing and financial constraints, working with customers to understand both their needs and the conditions under which the product will be used, understanding the engineering and production constraints induced by a manufacturing plant, and so forth. In addition, the students gain experience with a multidisciplinary team, where engineering, computer science and business expertise is needed for a successful product. And, it provides an unparalleled opportunity for business/entrepreneurship students to understand the intricacies of the design process².

All these functions—multidisciplinary product design with entrepreneurial experience—are brought together in a course we recently designed and delivered. The course involved four mechanical engineering students, three computer-science students, and three entrepreneurship students in a two-semester course sequence. These students worked closely with a local engineering and manufacturing company, Pine Instruments, to develop a product to automatically measure and qualify aggregate for asphalt and concrete. This highly technical product posed interesting mechanical and computer-science problems, while giving the business students the chance to study a business-to-business industrial market. The course started with a semester of product planning (roughly one credit hour) followed by a three-credit hour course of lectures and product development. During both terms, the students worked closely with the company, getting access to market, financial, engineering, and customer information, just as they would if they worked for the company.

We learned a great deal about the advantages and disadvantages of teaching entrepreneurship using this approach. The students gained great appreciation for both the difficulty of getting a product out the door (they completed only a rough prototype) and the complexities of markets and understanding customer needs. They also learned to appreciate each other's disciplines. There were problems, however. It was difficult to get the students to work together (we call it the junior-high dance syndrome), the students tended to over optimize their components without regard for the product as a whole, and they did not fully appreciate the constraints of working

with existing intellectual property as well as existing engineering and manufacturing considerations.

Moreover, the class provided insight, stimulation, and an opportunity for faculty to collaborate in the design, development, and execution of a course that actually became fun for them. Engineering, computer science, and entrepreneurship faculty often have different instructional paradigms, ways of perceiving and solving problems, and personalities. The opportunity to collaborate with colleagues from different disciplines was a significant “value proposition” as our business colleagues say.

The paper provides details on our experience, including curriculum and instructional materials we developed, along with our suggestions for implementing such a class at a small college.

Context of the course

The course was taught jointly by three faculty members, one each from the computer science department, the mechanical engineering department and the entrepreneurship department. The faculty team collectively had industrial design, business and start up experience.

The inspiration for High Technology Venture Start-up, came from the Stanford Technology Ventures Program and The University of Michigan’s Program in Manufacturing. Both of these programs provide a blend of entrepreneurship, business, and engineering. Since our institution is a small four-year college with an undergraduate focus, providing the level of experience students at these schools get is impossible. We tried, however, to distill some elements into a three-hour, semester-long class. The most important elements for us to incorporate into the class were: working with a real company that designs, engineers and supports real products; multidisciplinary teams; and, developing a real product for real customers. In this way, our class has common features with those described by Ports, et al.³ and Carlson and Sullivan⁴.

Students at GCC, like students at most other engineering schools, are excellent at analyzing systems and designing solutions to small, well-defined problems. The constraints of most engineering and computer science classes do not give faculty the opportunity to teach *design*, particularly using a rapid-prototyping approach. We were inspired by schools like Carnegie Mellon that provide their students with a rich prototyping experience in some classes; similarly, we were inspired by the methodology of IDEO⁵, where prototyping is standard practice. As we describe later in this paper, prototyping was necessary for the students to understand not only the modules they were building, but, more importantly, the interfaces among these modules.

Moreover, we feel that multidisciplinary teams and prototyping create an atmosphere that encourages entrepreneurial thinking[†]. The large body of knowledge that students must master within their chosen areas of study often results in limited exposure to other disciplines. Involvement with a multidisciplinary team introduces students to the critical problems that their colleagues are attempting to solve as a new product is developed and introduced into the marketplace. Furthermore, prototyping can quickly validate good ideas, suggest improvements, identify problems related to the integration of various subsystems, and be used to gauge possible acceptance by the customer. Both multidisciplinary teams and prototyping foster a broader view of product development that is essential to the success of an entrepreneurial venture.

The product

Pine Instrument designs and builds a wide variety of industrial equipment and electronic assemblies. The company has a reputation for working closely with its customers over many years, and understands customer needs and product applications.

Pine Instrument produces a line of asphalt and aggregate testing equipment for field and laboratory quality control and assurance. One product for laboratory use measures the form, angularity, and texture of aggregates used in the construction industry (see Figure 1). This machine has a bed on which rock samples are placed by hand, and an expensive camera moves over each of the 50 or so samples, taking a digital photograph of each sample (see Figure 2). Each photograph is then analyzed to measure the characteristics of interest. While the machine worked, it suffered from the following drawbacks:

- Processing each sample took considerable time.
- Each rock had to be placed by hand, which required significant operator input.
- The machine was expensive since much of it was over designed. For example, the camera used a very expensive lens system that is unnecessary. In addition, the prototype used a very powerful desktop computer when a simpler, cheaper machine could have been used.
- The unit required human intervention every 14 minutes to load additional samples.
- Proprietary, third-party software had to be packaged and sold with every system.
- The machine was fragile, difficult to transport, and had a high parts count. It was intended to work primarily in a lab.

The original version of the product had production costs of \$26,000 with a selling price of \$30,000. The product always sold for full price. The relatively small margin, 15%, was the result of a misstatement by the inventor in an introduction of the product to the market when he quoted the price from memory, misremembering the original selling price was to be \$39,000. The misstatement set the market expectation and could not be undone. The company wished to decrease production costs in order to improve margins and take second and third generations of the product into ancillary markets that are more price sensitive than the current market.

The student design team was able to reduce production costs to under \$8,500 by replacing several expensive components with higher functioning yet less expensive components. Target price of the second generation machine was \$26,000 increasing company margins to 300% gross.

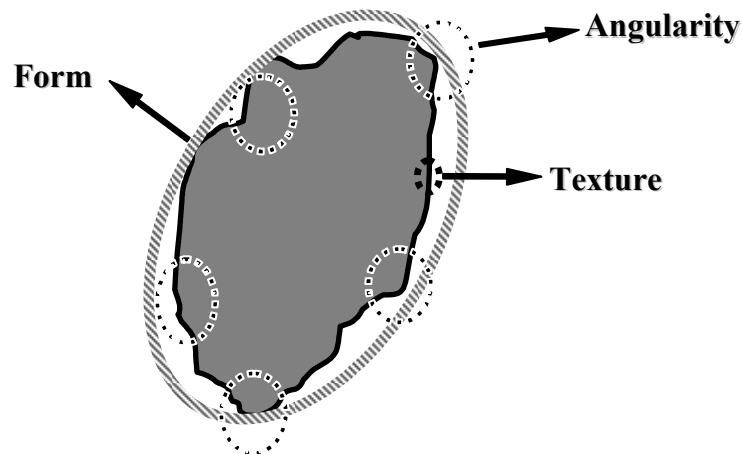


Figure 1. Key Aggregate Characteristics (illustration courtesy of Pine Instrument).



Figure 2. Existing Aggregate Imaging System (photo courtesy of Pine Instrument).

The students established product specifications independent of the way in which the existing system was implemented. The areas they focused on were the following:

- The entrepreneurship students did a complete survey of competitive products, determined the selling price, and identified several new markets where the product could be used. They also helped determine the product specifications.

- The engineering team decided to attack the user intervention and fragility problems. There were several reasons for this. Firstly, the entrepreneurship students identified several markets that required operation in harsh conditions (such as at a rock quarry) and required mobility from site to site. Secondly, customers wanted a machine that could run for hours examining rock samples without operator intervention. This required that the rocks be automatically loaded onto the bed where pictures could be taken.
- The CS and engineering teams attacked the problem of high cost by replacing the expensive camera with two inexpensive cameras and by developing a single software system instead of using the prototype's propriety software, which was more complex than necessary. By replacing some of the camera's functions with software, cost could be reduced.

The machine that the students designed and prototyped was vastly different than Pine Instrument's system. The student prototype used a vibratory bowl feeder to bring rocks from a large hopper to a trough where two inexpensive cameras examined the aggregate that proceeds one piece at time past an observation location (see Figure 3). This reduced operator intervention tremendously, and it also improved the systems robustness, as the hopper, conveyer and cameras were all designed to work in harsh environments.

The entrepreneurship students identified two national competitors whose products were 50% and 100%, respectively, more expensive. However, none of the competitors had comparable products in terms of functionality of the existing product; both competing products were far exceeded by the prototype the student team developed.

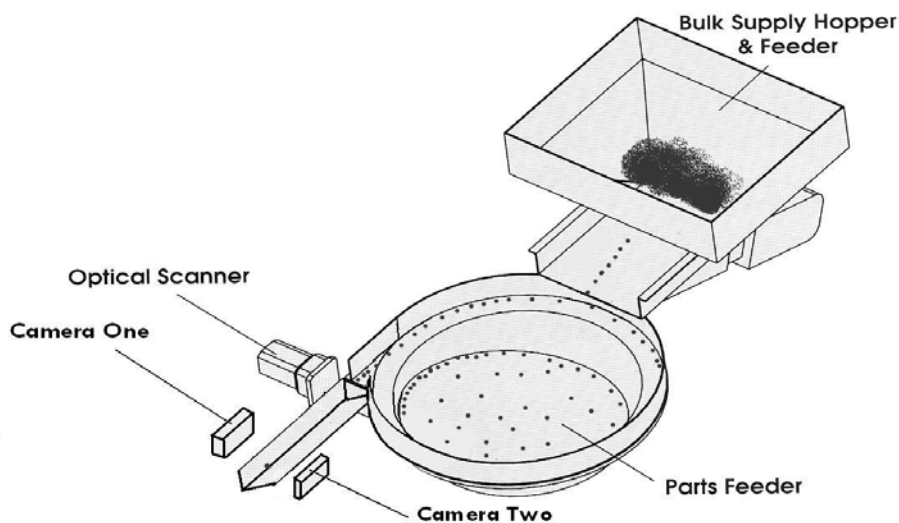


Figure 3. Prototype Aggregate Imaging System.

Pedagogy

There are five significant elements to our pedagogy; the use of cross-disciplinary student teams, a two-semester format, instruction across-disciplines by faculty, the mix of academic—lecture

and textbook—content with practical “lab” work, and, unique to this course, the extensive engagement of line managers of the partnering company.

The students in the class were composed of senior computer science majors, junior mechanical engineering majors, and junior entrepreneurship majors. The students were all chosen by the faculty based on their high competence in their respective major, creative spark, work ethic, and the ability to work in teams. Thus, the students were uniformly good to excellent.

We used these criteria for selecting students for several reasons. Firstly, we did not want to spend time on material that was domain specific (there was an exception to this, as noted later), and we wanted students who could complete reasonable tasks in their discipline. Secondly, we wanted to concentrate on design in the context of product development to encourage creative, entrepreneurial thinking. This is possible only when students have acquired reasonable competence in their field of study.

Work ethic was an important element as this was the first course offering and we could only estimate the direction of the course and workload. Actual execution and management of the course required periodic tweaking and we needed students who would commit and adjust the time and demonstrate the flexibility necessary for the course to be successfully. Furthermore, they needed to live with some ambiguity in both product specification and the syllabus. Finally, we wanted students that would work well together, as well as work well with the sponsoring company.

The course was divided over two terms, fall and spring. In fall term, the students and faculty met with representatives from Pine Instrument about five times to lay out product ideas and visit their facilities to understand their business and production constraints. The product-planning meetings were done informally, usually over lunch with each meeting taking about two hours. At the end of the term, the product idea was agreed upon and rough designs were drawn up.

In the spring term, we met for a single three-hour class once per week. We treated the lectures informally, and encouraged discussion, of which there was plenty. We also tried to make the lecture material relevant to the project. The lectures were divided up as follows:

- The first five lectures of the term were devoted to design and rapid prototyping, using Kelley’s book on IDEO⁵ and a number of short case studies. We covered topics such as disruptive technologies, how to really understand customer needs, prototyping methods, and technology leadership. These lectures and accompanying discussion lasted for about one and a half hours, with the remaining time spent working on the project. This included time in the mechanical engineering lab fabricating the prototype, showing demonstrations, and getting reports on potential markets and design specifications.
- We then spent about six lectures on entrepreneurship, marketing, and finance from Dorf and Byers text⁶. Some of this material was familiar to the entrepreneurship students, but we thought it so central to the class that we included it. Furthermore, it was particularly important for the engineering students to understand how business works.

Consequently, we utilized the entrepreneurship department's relationship with a regional technology angel investing firm, Blue Tree Investors, to give the students firsthand experience with capital raising. The class was allowed to sit in on business-investment presentations, hear experts and investors queries, and even participate in the discussion. Two technology based-ventures were presented by the founders/management teams, and one follow-up review was conducted. Students saw the presentations, then listened to the investors questioning the founders, and then, most importantly were permitted to hear the internal investor discussion once the presenters had left. This enabled the students not only to see potential models, but to understand the key issues business investors consider.

Especially illuminating to the engineering students was that key questions were often *not* about design issues, but about marketing and management issues. Revealing to the business students was the depth the technology discussion by the investors and the field experts they engaged in the question period and discussion to ensure they grasped a complete picture of the technology proposition of the presentations.

- We had presentations from, and question and answer sessions with, the line managers of Pine Instrument. These presentations and discussions concerned the product content. The managers set the climate by their demeanor and interactions. These initial presentations were supplemented by subgroup meetings with student teams and numerous phone and email exchanges.
- The remainder of the lectures were spent on the project, typically in the lab or meeting with staff from the sponsoring company.

An important instructional element was the engagement of the line managers. From formal meetings to informal phone and email exchanges they brought the “real world” element of the course home. While the faculty all had worked in industry and are active consultants, the involvement of the line managers brought the students into the world of business.

The assignments consisted of regular status reports and intermediate design documents, along with weekly reading quizzes. These assignments were lightweight, since the emphasis was on the final prototype. The status reports were submitted in irregular intervals, as different student teams would hit snags making it impossible to submit the reports according to the course schedule. Given the nature of the class, we expected this to happen.

The students spent considerable time working in their discipline-specific groups developing either modules for the prototype or working on various elements of the business case. The students were responsible for meeting with cognizant faculty at least once every two weeks to discuss progress and problems. Often, these meetings occurred several times per week.

At the end of the term, the students presented their prototype to Pine Instrument. We worked quite intensely with the students over several days on their presentations, reviewing their slides, coaching them on presentation style and questioning them. Frankly, most of these sessions were not quite a train wreck, but close enough to leave us concerned. At the final presentation, however, it all came together and the students made a very professional and effective presentation. The prototype was neither fully working nor integrated, but enough was completed

to demonstrate the major product concepts. The entrepreneurship students made a good business case.

A final element of the instructional process was entry and submission of the business plan into the campus competition. This element provided a reinforcing deadline for the project and expert feedback from an external source. If the student team had been selected as a finalist in the competition they would have had a duplicate experience to what they observed at Blue Tree; only this time they would have been in the hotseat.

Experience

We felt that the teams performed well in their respective areas. Yet, we were not able to get them to work together as well as we would have liked. Generally, the teams worked in discipline-specific groups, and even our attempts to get them to mix during prototyping sessions were less than successful. We termed this the “junior high dance effect,” except that rather than sorting by gender, the students sorted by discipline; a problem that appears to plague other multi-disciplinary classes like ours⁷. We were particularly disappointed in this effect at the early stages of prototyping, which were not particularly technical. The entrepreneurship students did not participate well, perhaps because they felt outgunned by the engineers, yet they understood the product specifications the best of all the students.

To garner experience in design and to try new concepts, we encouraged our students to spend time creating prototypes out of Styrofoam, paper, and tape; the CS students were encouraged to get modules running without writing detailed specifications (employing agile methods) or doing much analysis so they could “see what happens.” This was particularly useful as neither the CS students nor the ME (nor the faculty or company sponsors) fully understood all that was required for the product. In particular, the interfaces among the computer, the mechanical components, and various electrical components all needed to be worked out. Thus, it was impossible to fully analyze the system, as we did not have a complete model.

Moreover, while we all believe that theoretical analysis has its place, we wanted to foster an entrepreneurial spirit in the student teams by encouraging them to think of solutions, and not be hindered by analysis. We felt that attempting risky solutions was to be encouraged by us, but realized students would be reluctant if they felt they did not understand the mathematics behind their solution. For example, we had to develop a novel lighting system to properly illuminate the rocks as they were being photographed. It is nearly impossible for undergraduates to theoretically analyze such a system, yet they could easily build it and see how it worked.

One of the lessons all the students learned was the importance of cost. Since the students wanted to reduce the cost of their machine compared with the original system, they learned how component costs must be closely monitored. In addition, they learned about all the additional costs that get loaded into product costs, such as inventory, engineering, warranty, and insurance. The engineering and computer science students were astonished at all the things that that must be considered in calculating the cost of the machine.

We were very fortunate to have chosen the right company to work with. Pine Instrument’s staff were very willing to work with us, as we were feeling our way through the class. We met

regularly both on our campus and at their facilities. They were quite frank with their assessments, yet were willing to help fix any problems. This was quite successful because Pine Instrument had a good sense of what the product should do, how it should operate, and what it should cost. Thus, they could measure the students' results.

What worked?

Three things worked so well that they should be noted; the faculty team, the client company and line manager team, and the specialty nature of the course.

- The faculty team turned out to be an excellent complement of personalities and perspectives. The ability of the faculty to work together, exchange ideas, challenge perspectives and assumptions, etc., fostered a very productive and collaborative effort.
- The team from Pine Instrument consisted of professionals who were genuinely interested in the students' education. While the project offered the firm a value proposition, they made themselves available to students and faculty, focused on helping students understand the product and the business, and provided specific substantive feedback on all elements.
- As a specialty or "studies course" for which students had to be selected, we were ensured highly motivated, interested students. These students enabled us to regularly call "audibles" in the course execution and they moved with the flow and adjusted accordingly.

What needs some work?

While we are refining the course and bringing it back as part of the standard curriculum, three items needed to be addressed: cross-disciplinary student team work, managing team work, course content and focus.

- Cross-disciplinary team work. While there was always cooperation and communication, the students tended to gravitate to their peers. We established discipline-based teams and expected them to work across disciplines. In our next rendition, each team will consist of one student from each academic discipline to foster cross-disciplinary work.
- Managing team work. All three faculty were teaching in an overload capacity and as a result tended to let the student teams manage themselves. This resulted in a few occasions where students were not ready to meet deadlines that then impacted what other teams could do. While there were periodical check points, we trusted rather than verified. This reduced faculty stress during the semester, but resulted in a few peak stress points when teams and faculty scrambled to catch up. One team member catastrophically let her sub-team down by doing nearly nothing until the last minute, and that team was not able to fully recover. This was a failure of the faculty member who accepted the "yeah, I'm right on track," instead of asking to see her portion of the research and report.

- Course content and focus. We need to reduce the amount of time spent on innovation and incorporate it as subsets of other lecture material⁸. We need to ensure the design process is clear to and usable by the business students and the business model/plan process is clear to and usable by the engineering students (perhaps adapting an approach similar to that used by Nichols et. al⁹). While all these concepts were explained, there was evidence that students fell back into their comfort zones and let the business students focus on business and engineering students focus on design.

Summary

The course is now offered as a regular course. We will still admit students selectively, but presenting the course as a regularly offered course with its own course number permits students to plan for it in their course rotation. A regular course also give it higher priority in the students view; our students sometime treat studies courses as secondary concerns: when crunch time comes in the semester, these courses suffer from inattention as students focus on major and core requirements.

The client company and the constituents of the faculty team are critically important. The client company with a commitment to the educational process creates additional instructors, lends a better learning atmosphere than when the company is only focused on their outcomes, and guidance and feedback is conveyed with the purpose of student learning.

The personality and perspective mix of the faculty team is key. The faculty need to trust each other especially when a team member wants to or is doing something the others cannot quite get their hands around. Moreover, they need to give credit if a part of the class works and encouragement and support if it does not.

Finally, the students worked hard and achieved a significant, albeit not complete, system. To a person, they felt the experience well worth it. Most importantly, the students developed skills in areas outside their specialty, an essential quality for today's engineers¹⁰.

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[†] By Entrepreneurial thinking we mean “the process of a) identifying opportunities others do not see, b) assessing those opportunities – identifying necessary human, financial, and other resources necessary to exploit the opportunity, c) evaluating and managing the inherent risk in the new opportunity and d) persisting in pursuing of the opportunity to realization.”