AC 2007-1147: AN INTERDISCIPLINARY APPROACH TO COMPLEX PRODUCT DESIGN PROJECTS

John Farris, Grand Valley State University

Paul Lane, Grand Valley State University

An Interdisciplinary Approach to Complex Product Design Projects

Abstract
In 2004, the Padnos College of Engineering and Computing at Grand Valley State University launched the Product Design and Manufacturing emphasis. The new program was created in response to the local industry demand for engineers educated to take a product from conception to production. To meet this challenge, the program was designed with an emphasis on real world, innovative, multi-disciplinary product design and build projects. More than developing products, the program desires to develop business opportunities that will lead to local economic development. To implement these projects, the following challenges had to be overcome:

1. A stream of innovative product ideas had to be generated and sustained.
2. Since the products are innovative, the program had to be able to deal with the partial success of a product prototype or concept.
3. The interdisciplinary nature of product development had to be replicated in the functionally divided university setting which contained significant opposition to classes that integrated different disciplines.

This paper describes a system designed to overcome these obstacles. The development of a complicated consumer product, a coffee maker that can roast, grind, and brew coffee, is used as an example to illustrate the strengths and weaknesses of the system.

Introduction

Successful products are developed by interdisciplinary teams of professionals shepherding the product concept from identifying customer needs to first production. Industry has found that this holistic approach shortens development time, reduces costs, and delivers a product that more closely meets customer expectations. The interdisciplinary teams can quickly deal with the complex interplay between customer needs, product cost and expected quality. With a few notable exceptions, academia has been slow to adopt a similar approach.[1,2]

Academics have traditionally been highly educated specialists with very little incentive to reach across disciplinary boundaries. There are several significant

obstacles that must be overcome to create an environment similar to industrial practice. The engineering schools are often reluctant to devote precious engineering credits to an interdisciplinary experience. Technical electives at some institutions have been crowded out by a combination of high general education course requirements and state mandated caps on the number of credits required to graduate. On the business side, strict accreditation requirements from The Association to Advance Collegiate Schools of Business (AACSB) limit the business schools' ability to offer innovative courses with faculty from other disciplines. Many of these complications can be overcome with a little creativity and extra resources.[3]

Unfortunately the cultural differences between Engineering schools and Business schools are harder to overcome. The issues stem from the differing expectations of students, professors and administrations. Business and engineering students often have differing expectations about grading and workload requirements. Similarly business and engineering faculty often have differing expectations about how much of the course should be devoted to project work. Finally the administrations of the business and the engineering schools may have different ideas about the appropriate number of students required to offer a class. In addition, the schools cultures may tolerate different amounts of student dissatisfaction with high expectations required to successfully complete an interdisciplinary project.

This paper describes a system designed to allow a school that has not overcome the obstacles to implementing interdisciplinary product development teams to take the first steps in that direction. Two core beliefs form the foundation for this strategy. First, students from different disciplines can develop not only products but business opportunities to enhance the local economy. Students or local businesses may be the beneficiaries of these business opportunities. Second the experience students obtain developing these business opportunities prepares them to participate and lead product development teams in industry. A flow chart of the strategy is shown in Figure 1.

The iterative nature of the system allows students to tackle more complex, innovative and realistic product development projects. This is important for the following reasons:

1. Potential employers desire student who have experience developing complex products.
2. Developing complex products forces students to confront difficult technical and market challenges.
3. The principles of product design and development are better illustrated with complex products than with simple products.
4. Complex products require iteration to reach a satisfactory solution.

Product Ideas

The input to the system is a steady stream of product ideas. Since many ideas will not be appropriate for further development by students, it is essential to be able to choose from a large number of potential projects. In this model product ideas are gathered from sources that are within and beyond the university. These sources include:

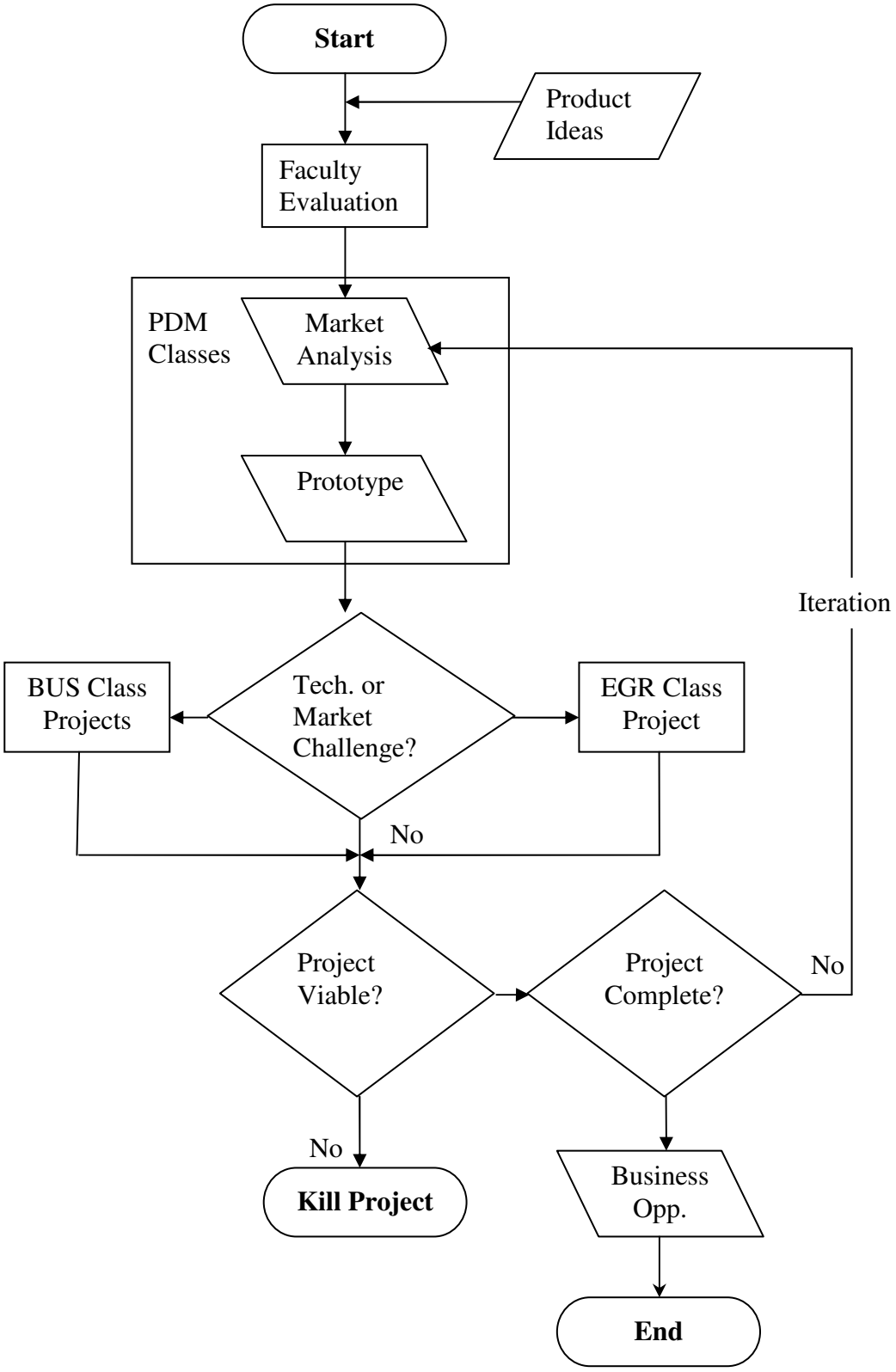

Figure 1. A flow chart of a system to develop business opportunities.

1. Inventors referred by the Small Business Technical Development Center (SBTDC) that is located on campus.
2. Local companies seeking to explore new markets or new technology with little investment or risk.
3. Students enrolled in the entrepreneurship minor on campus.
4. Faculty from other disciplines who have ideas for new products.
5. Engineering faculty and students.

An example of a product idea that was selected for development is the concept of a coffee machine that would roast, grind and brew green coffee beans. The idea originated with a student in the entrepreneurship minor. Later a business faculty member who had just returned from Nicaragua embellished the idea by suggesting that the coffee machine could be used to create an alternate, more lucrative market, for Nicaraguan coffee beans. The professor thought that the coffee maker could be sold with a subscription to green Nicaraguan coffee. After purchasing the coffee machine, the customer would receive a pound of coffee in the mail every month. The coffee would be accompanied by a newsletter describing the origins of the coffee and the lives of the people responsible for growing and processing the coffee. The newsletter would also contain the web address of a site that contains more information about Nicaragua and a method to order more green beans. The newsletter and web site would be designed to forge a bond between the coffee producers and consumers. At this point the idea entered the system.

Evaluation of Product Ideas

After gathering many product ideas, a few ideas must be selected for development. Choosing the most appropriate projects is difficult and has a large influence on the quality of the students' experience. Some criteria that should be considered before selecting a project include:

1. Is the scope of the project appropriate? Too small a scope is more detrimental than too broad of a scope. Student teams can always restrict their attention to a subset of problems to solve and leave some problems for the next iteration. On the other hand teams become very dissatisfied when the scope of their project must be broadened.
2. Is the level of difficulty appropriate for students?
3. Is there more than one reasonable way to design a solution? Generating alternative design concepts is the focus of many product design classes. If one superior concept exists, the students will be deprived of the experience of applying engineering analysis to determine the most appropriate concept.
4. Is the product idea in an area where faculty or students have an interest? Most successful projects have at least one passionate advocate.
5. Is an external project sponsor available and willing to mentor students? Student teams are very motivated to please external sponsors.

More than one person should rate and select projects. Unfortunately few projects will meet all of these criteria well. Knowing the shortcomings of a project helps the faculty devise methods to compensate and minimize the problems.

The coffee machine project has a very large scope, many possible solutions and a passionate project sponsor, the business faculty member who had been to Nicaragua. For these reasons the coffee machine was selected for development.

Market Analysis and Prototype

The next two outputs of the system described in figure one are a market analysis and a prototype. These outputs are produced by teams in a junior level, engineering, product design class. To complete a market analysis the students must determine the core benefit of the product, define a target market, solicit the opinions consumers in the target market and research the competition. The market analysis is performed to answer the following questions:

1. Who is the target market?
2. Does the target market desire the core benefit of the envisioned product?
3. How do customers achieve the core benefit without the envisioned product?
4. What benefits and features are important to the potential customers?
5. How do potential customers believe they would use the product?
6. How much are consumers in the target market willing to pay for a product that delivers the core benefit?

The idea of consulting customers is often new, frightening and exhilarating for engineering students. Just like the real world, the response of potential customers can surprise students, faculty and project mentors. Techniques for getting this information are well documented in business and engineering texts.[4,5] Since the class must also produce a working prototype, few potential customers are consulted, but the insights obtained from the potential customers forces the students to modify their design ideas.

In the coffee machine example, the core benefit of the coffee machine was initially identified as its ability to provide the freshest possible cup of coffee at home. The target market was described as socially conscience women between the ages of thirty-three and sixty-five 65 from dual income households with an annual household income of greater $75,000. These women are educated professionals who are interested in healthy living and organic foods. These women appreciate good coffee and other quality products but also identify with the plight of the coffee producers.

Some of the findings from the initial market analysis for the coffee machine were:

1. The machine should be as small as possible.
2. Potential customers are not interested in becoming expert coffee roasters and brewers. They want the machine to handle the complexities of the process.
3. Customers are not interested in seeing the machine operate.
4. The smoke and smell problems with current roasting technology has limited consumer adoption of home roasting.

Once the market analysis is completed, the student teams design and build a functional prototype. The performance of the prototype is measured against the specification developed from the market analysis. Part of this analysis requires the student team to determine the most serious unresolved technical or marketing challenge. The creation and evaluation of the prototype brings technical and market challenges into sharp focus.

For the coffee maker project, six teams of two students designed and manufactured devices to meter the beans, roast the beans, contain the smoke and smell produced from roasting, expel the roasted beans, grind the beans and brew the coffee. The teams collaborated to combine their subsystems into a comprehensive prototype. Each team deployed different technology with varying degrees of success. The technical challenges identified by the students included fitting the subsystems into a small package, containing the smell of roasting the beans and managing the heat required to roast the beans. On the marketing side the students were unable to determine with any confidence how much the potential customers would be willing to pay for a machine that roasted, ground and brewed raw coffee beans.

Technical or Market Challenge Leading to Class Projects

Performing the market analysis and creating a prototype allows student teams to easily identify technical and market challenges. These challenges can be refined to become the subject of class projects in more traditional engineering and business classes. Many professors are not eager to attempt to solve open ended problems as class projects. These professors have little experience tackling open ended projects in a classroom setting and they are concerned that the solutions will require knowledge not covered in the class. The refined technical and market challenges become well defined projects for the more traditional business and engineering courses. The results of these projects are used by future student teams to complete the product development project.

A few examples from the coffee machine product development project show how the process can work. Students who created the bean metering and roasting devices quickly learned that metering, and roasting the beans was not difficult but transporting the beans between processes while minimizing the overall size of the product was difficult. This technical challenge became a focused class project in the advanced product design class. Similarly the students discovered that containing the odor generated during roasting the beans was very difficult. The strategies they used did not function well. This technical challenge became senior research topic in the chemistry department's capstone class. In addition, improving the control system was identified as a difficult challenge and a team of electrical engineering students undertook the design and manufacture of a circuit board to control the roasting, grinding and brewing processes. On the business side, the original team could not determine, with confidence, how much potential customers in the target market would expect to pay for a machine that produced the freshest possible coffee at home by roasting, grinding and brewing green coffee beans. A new product marketing class that tackled this challenge also discovered that the potential customers valued the connection to the coffee farmers as much as the machine's ability to produce the freshest possible coffee. This insight, as well as other information produced by additional business class projects, will have a significant impact on the next iteration of the design of the coffee machine.

Iteration

When the results of the focused projects are received, new student teams are charged with critically reviewing the new information and redesigning the product in response to the new information. The critical review of previous work forces students to evaluate the work of their peers. The students review the documentation, techniques employed and results. The teams then make plans to gather information and confirm questionable conclusions in the previous work. This work leads to a revised set of specifications that are the basis for redesigning the product.

Iteration is a difficult concept for students new to product development. Students do not have experience iterating. Most engineering classes focus on analysis and problem solving. The problem is either correct or incorrect. Product design is different. Many designs may be satisfactory. Some designs meet the specifications or needs of the customer better than others. Students and faculty learn a tremendous amount by building the first prototype. The second prototype is always a large improvement. The value of iterating is an important lesson to anyone interested in product development.

Kill the Project

Endless iteration is not the goal, at some point the market or technical challenges may prove insurmountable and the development of a product must be stopped or in product development terms "killed". Consumers may not be willing to pay a high enough price for the product to justify production. Perhaps the current technology can not deliver the benefit customers desire for a price they are willing to pay. This determination is best made by a team of faculty or a team of students new to the project. Students who have invested time and effort in a project are reluctant to kill the project.

Fortunately the coffee maker project has not reached this point yet, but it may. Killing a project is never an easy decision. One of the first products to go through the process was a prescription pill dispenser. The population in many developed countries is aging quickly while the number of prescription medicines available continues to rise. A quick survey revealed that many elderly people were taking more than 6 prescription pills a day. Each prescription required a different regimen. Some pills need to be taken once a day, some three times a day and some once a week. The consequences of missing a dose can be serious. Furthermore a preliminary market survey showed that elderly patients, their care givers and their children all worried about the consequences of missing a dose. The situation seemed like a promising product opportunity. Three engineering teams developed methods to separate pills from groups of identical pills and dispense pills. One team of marketing students and one team of entrepreneurship students worked with potential customers to determine their needs and get reactions to successive prototypes. After four semesters of work, the conflicting customer requirements forced the abandonment of the project. A technology could not be developed to meet customer requirements for a price customers were willing to pay. The decision to abandon the project does not mean that the time and effort of the students and faculty were wasted. Project participants learned a great deal from the effort. It is important to remember that preparing students for successful careers is the purpose of these classes. A few companies continue to devise products to exploit this opportunity. Former students often send describe products developed to fulfill this need. These former students are always quick to analyze the product and handicap its chances of success.

The Business Opportunity

Since one of the goals of this system is economic development it is important that successful projects are handed off to individuals or organizations that can capitalize on the opportunity. For projects that come into the system from individuals or companies the hand off is easy. For student driven projects, appropriate support systems must be found. Fortunately Grand Valley State University (GVSU) has an active Small Business Technology Development Center

(SBTDC). Students can get excellent advice and guidance on how to shepherd their project to the market. Students who lack the experience, resources or experience to commercialize their products can also turn to the Innovation Committee. The Innovation Committee funds the development and commercialization of promising intellectual property developed by faculty and students at the GVSU. This service is not free. The committee negotiates a financial arrangement with the inventor. To date the committee has funded the provisional patents of two products developed by the system described in this paper.

The bigger challenge is determining how to continue a project when the inventor or intellectual property owner is no longer interested pursuing the opportunity. The problems involved in negotiating a sharing the intellectual property rights has caused long delays or even the abandonment of some promising projects.

Conclusions

A new model that allows students from many different disciplines to gain product development experience has been developed. The model allows students to tackle complex, real-world product development challenges. The advantage of the new model over some of the existing models is that the new model does not require the integration of many disciplines into one class. Although this integration is preferred, many institutions are unable to muster the required high level support to breakdown the academic silos that separate the different disciplines. The new model, although significantly slower in developing promising products, offers a step toward the ultimate integration of disciplines.

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