A Course in

ENGINEERING ENTREPRENEURSHIP

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THE DOMINANT TREND in engineering education for the last 10 to 15 years has been toward engineering science. Much of the research effort has been concerned with the development of new techniques to solve technical problems, the undergraduate and graduate curricula emphasize the available methods used to describe physical systems, and the laboratory courses are used to support the theoretical material presented in the lectures by demonstrating that experimental data generally agree with theoretical predictions. Although this increased effort to develop new approaches to problem solving has led to some significant advances in technology, it has been accompanied by a de-emphasis in the search for economic solutions to real problems. In fact, economic analysis of engineering problems is generally discussed only in a senior-year design course, rather than being integrated throughout both the undergraduate and graduate programs.

With these changes occurring in engineering education we are training students to have an appreciation for the fundamental methods of engineering instead of the actual practice of engineering. Since the practice of engineering usually requires efficient, economic solutions to problems that have never been solved before, a student needs to acquire the ability to recognize how to complete the statement of a problem, how to decide on the best approach, how to determine the required accuracy of any solution he develops, and how to sell his solution either to his management or to the public. Unfortunately, many present engineering programs ignore most of these questions. After entering industry, a student often realizes that the intuitive notions he gained from his courses frequently are more valuable than the quantitative methods, that it is often more efficient to solve a problem experimentally rather than undertake a theoretical analysis, that it is much more advantageous to use a highly directed approach to get quick answers to a problem rather than a scholarly understanding in depth, etc. Thus the university needs to find ways to give engineering students an enhanced ability to perform in the real world of engineering practice.

One approach we are using to improve the balance between theory and practice at the University of Massachusetts is to introduce an elective course in entrepreneurship, described below. The purpose of this course is to get students to generate ideas that they would then translate into commercial ventures. We anticipate that most of the projects will continue to be in such areas as household items or sporting goods because the students have a better overall background in these fields than they do in the chemical industry; for example, they are better able to relate to the problems of the expected sales price and potential total sales in the development of a new ski than in the development of new chemical products. Although we would prefer for a larger number of our students to focus their efforts on industrial chemistry, the advantages gained by having a student realize the balance between theory, estimation, experimentation, marketing, and sales in the quick and reliable solution of an unsolved problem seem to us to outweigh the disadvantages of deviating from a chemical orientation. Moreover, we have found that a high level of enthusiasm is generated in the students when they recognize the realism of the unsolved nature of the problem (compared to most laboratory exercises), the expected commercialization of the final product, and, of course, the necessity of the student to find the capital required to finance his venture. This capitalization requirement means that realistically we have to restrict our interests to projects having low investment costs.

To date we have offered this course on entrepreneurship on an experimental basis to a class of four "hand-picked" graduate students in a 3 credit hour course, and to eight freshmen in a 1 credit-hour course. These graduate students all had excellent grade-point averages, but very different personalities and interests. As might be expected, the student performance varied widely, and the performance seemed to correlate better

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with an interest in entrepreneurship or personality characteristics than academic background. We were highly pleased with the progress and performance of both groups of students. (We are investing our time and capital in several projects for future commercialization —the most sincere grade a student can be given.) Also we plan to expand it into an option in our Master's Degree Program and to offer the material to sophomores and more advanced undergraduates as a special studies program. It is too early to assess any improvement in the ability of the students to practice chemical engineering, although we are optimistic that an enhancement of these abilities is taking place.

COURSE DESCRIPTION

In a few introductory lectures we discussed some of the recent surveys that demonstrate the decreasing competitive position of the United States in the world market, the fact that over 100,000 manufacturing jobs have been lost in Massachusetts alone in the last 5 years, and the the role of engineering in improving this position. The purpose of engineering is to find ways to create new wealth, and often this is accomplished by translating scientific ideas into specific products that people will buy to make their lives more pleasant in some sense. One of the keys to the development of a new product lies in the original idea, but no idea has value unless it can be translated into a successful commercial venture. Therefore, the two main topics covered in the course were idea generation and the procedures required to develop and commercialize a new idea, termed idea exploitation.

Idea Generation

Most industrial corporations have an established organization to develop new products for the company. Normally they attempt to accomplish this goal by looking for new applications for existing company products, searching for new uses of by-product materials, hunting for new sources of raw materials, and evaluating the effects of modifying existing processes and products. The search for new opportunities is restricted to those that are in general conformity with the company's goals and past experience. On the contrary, a private inventor frequently possesses a broader range of interests in business opportunities, perhaps by finding out what frustrates people and looking for a product that will relieve that frustration, by close observation of how present devices work and then discovering a better way to do the same task, or by recognizing that a technique someone has used to solve a particular problem can also be applied to a new area. Thus a private inventor is limited only by his imagination and the extent of his knowledge. In class we presented numerous illustrations of published inventions in four categories: looking for applications of an existing body of the inventor's expertise, looking for ways to satisfy existing needs in the marketplace, looking for ways to fill "holes" in a market even though a need is not readily apparent, and looking for new applications of existing products or new ways to produce existing products.

After discussing a large number of examples of idea generation in class, we asked the students to generate some ideas of their own. We were very surprised at how well they did, and there were many more projects of potential than we had time to pursue. Similarly, the concepts of idea generation were presented in a Freshman Engineering Module (a four-week short course) and the freshmen also came up with some outstanding ideas. The students seemed to enjoy this part of the course tremendously, and it went very smoothly.

Idea Exploitation

An idea has value only if it can be translated into a commercial venture. About 59 out of 60 ideas that initially appear to be promising fail somewhere along the line, and frequently the marketing difficulties are much tougher to overcome than the technical problems. With a high potential failure rate it is necessary to find a way to screen ideas very quickly for both their technical and marketing potential, rather than to complete a lengthy technical development of a product and then find that it can't be sold. Thus the best approach to use in developing a new product is a method of successive approximations, sometimes called the engineering method, where an attempt is made to get a complete solution to the whole problem as quickly as possible by ignoring all but the most essential details of the solution; this procedure must be developed by practice in the course. If the results of this initial solution look promising, we then determine the most critical areas of the solution and attempt to fill in the details of the analysis. By using this approach of obtaining successive solutions, which are more accurate as more of the details are considered, we have the advantages of quickly dropping projects with little promise either from a technical or a marketing standpoint, of obtaining a rapid assessment of the critical areas of the development of the product, and of having a fast solution to the overall problem that we may be able to implement with an appropriate use of safety factors. Similarly, the application of the engineering method is normally the most efficient approach because even though we solve the same problem many times in varying degrees of detail, we avoid going down dead ends or wasting time in a lengthy analysis of parts of the problem that are not very important.

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A useful set of questions to consider during the initial screening of a project are: Is it technically feasible? Can it be sold? Is there a significant market? Has it been done before? In answering these questions, we simultaneously consider: How difficult will it be to commercialize? What are the critical problems to be solved? Answers to these questions should be determined initially only by guestimates or by order-of-magnitude calculations. It is somewhat surprising how many projects will be dropped after spending only an hour or so thinking about these questions. Of course, part of the reason for this rapid rejection is that projects compatible with the low levels of available capital normally yield a small profit; the amount of effort required to solve the technical and marketing problems, along with the uncertainties associated with the development, often makes the project not seem to be worthwhile.

Once a project has passed the initial screening test, it is desirable to take a more formal, although still iterative, approach. After the critical stages in the development have been identified, then it is reasonable to proceed through the line presented below:

1. Complete the statement of the problem and define the critical steps of the problem
2. Translate the problem into engineering or marketing terms (costs and values)
3. Make a sketch or diagram of the system or operation
4. Use the sketch to try to guess a better answer
5. List the assumptions you need to make to undertake the simplest possible analysis of the problem
6. Estimate a solution based on the assumption in step 5
7. Evaluate if the solution is reasonable
8. Determine the effect your analysis has on your original overall solution to the problem
9. Examine the importance of the assumptions you made in step 5
10. If your analysis still leaves you with the critical item of the highest priority return to step 1. Otherwise, rerank the priorities of the critical problems and apply the procedure to the next most critical item.

The list above should be considered only as a guideline since in many cases it will be possible to skip several steps, iterations will take place within the main loop, or the steps will be rearranged into a different order. Nevertheless, the list provides a useful guide, particularly near the beginning of a course when a student tends to get bogged down in sophisticated solutions to technical problems that are similar to those he encountered in his previous course work. In fact, it is a difficult matter to get a student to use order-of-magnitude calculations, when he knows that he could get an exact solution by solving a partial differential equation, i.e., there is a tendency to substitute many hours worth of straightforward but tedious algebra for one hour of thought.

COURSE OPERATION

WE WERE QUITE convinced, even with no experience in teaching this type of course, that it would not be possible to teach the practice of engineering by lectures alone; hence, the course was run as a mix of lectures and discussions of individual projects carried out by the students. The lectures were designed to be relevant to the stage of development of the individual projects and the presentations were so timed.

The initial four weeks of the semester were allocated to lectures on idea generation and the use of the engineering method in idea exploitation. During this time the students practiced "taking a problem apart" in generating about 100 ideas for exploitation in the home industry, ranging from basement finishing to the manufacture of plastic headboards for beds (the ideas need not be original, except to the students involved). The students then generated a number of ideas individually, conducted an initial screening of their ideas, and reported their results to the class. The other students in the class questioned their analysis and the class as a whole held a "directed" brainstorming session. Here we tried to reevaluate the potential of the idea, to look for avenues providing even more profitable operation, or secondary problems that could be attacked if the original one failed. Then each student chose a project and started to proceed toward the commercialization of his idea. Class periods were spent by having the students define the critical problems of the moment, to present the priorities they placed on these problems, to discuss how they used the engineering method to solve the problems, to illustrate the kinds of order-of-magnitude calculations they found to be helpful, and to describe the work they planned to pursue. A significant number of comments were offered by the remainder of the class, and the teachers used this direction as a primary vehicle for teaching the practice of engineering. The students claimed that they learned a lot about "problem solving" from this part of the course, and we feel they progressed significantly as engineers.

Of course, the students often encountered problem areas where they had no background, such as procedures for obtaining patent protection or how to start a corporation (as well as the cost of these endeavors). The students thus learned how to quickly learn specific points of information in foreign subject areas; the faculty also provided some such information in a lecture format. We

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expect to broaden the presentation of information of this type next year when we plan to start the Master's Degree Program because several faculty in the School of Business Administration will also participate in the course.

CASE STUDIES

Several case studies have been generated which we plan to continue using as an illustration of the practice of engineering. Due to space limitations, the two studies that we have chosen to present here failed rather early, allowing a short but relatively complete description of the problems. We also have longer failures for class use. All successful projects are still being pursued by the students after termination of the class, and will probably not be recycled as case studies for at least a year.

Manufacture of Maple Syrup in the Home

As an initial example of idea generation, Dr. Douglas told the students about his ten year old son's attempt to make his own maple syrup. Using sugar maples in his front yard, a tap which cost 25 cents and a plastic milk jug to collect sap, it seemed to be a low cost venture to produce maple syrup by boiling off 40 parts of the sap to the one part retained as syrup. However, when Dr. Douglas returned from work every day to find the kitchen literally filled with steam, when he started to worry about the effect of the steam on the woodwork and the wallpaper, and when two pans were allowed to boil dry and were ruined, he was convinced that there must be a better way to make maple syrup at home. Thus the students were asked "What should we do about the problem of developing a home unit to make maple syrup?"

Solution

Most students seemed interested in the problem and realized that their chemical engineering background could be helpful to them, as they envisioned problems of evaporation and level control. They quickly realized that, by leading a hose from the top of the pot to an aspirator on the kitchen faucet, it would be possible to relieve the problem of steam filling the room and also increase the rate of evaporation by pulling a vacuum on the system. Then they developed a wide variety of devices for automatically measuring either the viscosity or density of the material in the pot and turning off the stove when the end point was reached. Hearing their tentative approaches to the problem increased their interest in doing additional work, and several students proposed conducting some experiments to gather information they thought might be useful.

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In our critique at the end of their first attempt to develop a solution, we noted that the most natural tendency for people with their background (they were all Ph.D. students) was to quickly become immersed in the technical details of the problem and to forget everything else. However, when we discussed the initial screening procedure with them, all students were confident that all the technical problems could be solved, even though they didn't examine any specific techniques for doing so. Moreover, one student suggested that a unit could be made to sell at about $15 because large automatic coffee makers with thermostatic controls were available at that price. All the students agreed that they were fairly certain that it hadn't been done before and from the relative success of home ice cream makers and home wine making kits, they thought that a home maple sugar kit, including tap, bucket, and evaporation unit, could be sold if the price was right (considerable less than $15). However, they recognized that the potential market was extremely small because it was limited to the population in New England, or similar climates where sugar maples were available, that there would be few sales in large population centers such as cities or their suburbs because not many sugar maples existed in those locations, and that many farmers would not be interested because they made their own syrup for sale. Thus the major market was in small towns in New England, and the profit potential associated with the size of this market seemed to be so small that they would prefer to consider other ideas that might be more lucrative.

After reviewing the results of the screening procedure, the students admitted that they had a whole new perspective on engineering analysis. They realized that no matter how elegant a technical solution they might have devised, the market limitations probably would have made this a wasted effort. Similarly, they were convinced that they could make estimates of the technical feasibility of some projects without worrying at all about the technical details and that it was possible to establish an approximate retail price of the product by analogy with the cost of an electric coffee pot.

Cigarette Filters

In early 1972, the Surgeon-General of the U.S.P.H.S. announced that cigarette smoking had begun increasing again, and that a more effective filter must be devised if we are to protect the populace from the tars and nicotine thought to contribute to lung cancer.

From our experience in the oil industry, we realized that tars and nicotine were simply basic aromatic compounds. Furthermore, such compounds have traditionally been removed from process streams by adsorption on high surface area solids, such as charcoal or clay. Charcoal is, of course, a component of one present cigarette filter. However, we reasoned that a high surface area solid acid, such as silica alumina or zeolite, should be even more effective. One of our students was thus assigned the task of making a preliminary evaluation of this proposal in two days, under our direction.

Solution

The obvious question relating to the marketability of a new cigarette filter is the cost of the absorbent per pack of cigarettes. Using the volume of charcoal in a Lark filter, the assumption that the new adsorbent could be used in the existing plastic cap on Doral cigarettes (or an equivalent specially manufactured cap), and the present market price for zeolites (the most expensive of the solid acids under consideration), we calculated that the incremental cost of the filter would be less than ½ cent per pack. Hence, the project was deemed to be sufficiently reasonable to define how the effectiveness of the new filters could be tested.

To determine how tars and nicotines are evaluated for cigarettes, in one day we called without success, the following:

(1) The U. Mass. Public Health Department; (2) The Mass. Dept. of Public Health; (3) the U. Mass School of Pharmacology; (4) The FDA office in Boston; (5) The U.S. Treasury, Alcohol and Tobacco Dept.; (6) The R. J. Reynolds Tobacco Co.

Finally we called the Tobacco Institute Testing Laboratory, where we talked to a laboratory technician who gave us a complete discussion of the gravimetric technique used as well as literature references describing the test.

That night we looked up the Journal of the Association of Official Analytical Chemists to find the specifics of the tar and nicotine test. We found that a smoking machine is used to test 10-20 cigarettes to obtain an average tar and nicotine level. The smoke is drawn through a commercially available filter unit; a volume of 35 ml. of smoke is puffed for a duration of 2 secs, once each minute. The filter paper is weighed before and after 10-20 cigarettes are smoked, the weight gain representing total tars, nicotine and moisture. The filter paper is soaked in an isopropanol-ethanol solution for extraction of water; the water content of the solution is determined by gas chromatography. The solution is then steam distilled to remove alcohol, and the nicotine then steam distilled from the tars; the nicotine content of the distillate is measured by infrared absorption at three wavelengths. The amount of tar is obtained by difference.

It became quickly apparent that we could neither duplicate this procedure in our laboratory nor afford the expense and time delay of sending our experimental filters to an independent testing laboratory. However, in reviewing the reported magnitudes of the tar, nicotine, and water levels on the filter paper, we realized that the water represents only 20-25% of the weight gain of the filtered paper. Since we were interested in significant improvements in tar and nicotine levels (e.g. up to 90% reduction of present levels), it appeared likely that simple measurements of the total weight gain of the filtered paper would be sufficient to indicate filter performance; the involved analysis procedure could be used to confirm the performance of those filters which were superior in our simpler tests, and those detailed tests would be performed by the Tobacco Institute Testing Laboratory.

Having established that our solid acid adsorbent concept was economically feasible and that a simple and inexpensive testing program could be initiated, we next turned to the patent literature to determine if such concepts had been previously invented. Much to our chagrin, we found not only 200 patents disclosing cigarette filters but also a 1958 patent covering the use of zeolites in cigarette filters and several more recent patents improving on this idea (e.g. changes to prevent the zeolite from drying out the tobacco, to prevent the adsorption of low molecular weight aromatics contributing to taste, etc.). At this stage, after about two man-days of effort, the project was abandoned.

Even though this project was terminated after only two days, the activity was of value to the student. They had learned to rapidly define the critical steps in an investigation, to simplify complex tasks for initial screening purposes, and to rapidly assimilate information in an unfamiliar field. We suggest that these are among the diagnostic arts important to the successful practice of engineering. Other important areas, such as the methods the student would use to sell his idea to tobacco company management and the relative importance of marketing, were not covered in detail with this problem. These items are more logically pursued with other, more successful, projects.

CONCLUSIONS

Obviously it would be nice to be able to say that several projects were brought to a successful completion during the course. However, the students appreciate the fact that an actual attempt at entrepreneurship will make artificial university time schedules meaningless, and they were willing to continue their efforts throughout the summer. Similarly, it might be of interest to describe the projects that appear to have sufficient promise that we are willing to supply our own capital to finance them, but one thing an entrepreneur learns very early in the game is to never reveal promising ideas until they have been exploited and sold! Nevertheless, we hope to make some successful case studies available in the not too distant future. □

COONEY (Continued from page 165)

exchange across the respiratory membrane.

For a discussion of artificial oxygenators, no suitable reference has yet been found. A chapter by Galletti[8] in the Advances in Biomedical Engineering and Medical Physics series has been used. However, this treatment is not aimed at the novice and is not appropriate. A welcome addition to the to the biomedical literature would be a paper containing illustrations and describing the available oxygenator designs (film, disc, membrane, bubble) in simple, clear terms. The mathematical modeling of oxygenators is normally given some treatment, but not any extensive elaboration. This is an area which soon becomes complex and is best left for advanced courses.