Innovation-Stage Projects for Undergraduate Engineers, Defining Mission Through A Focus on Innovation

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Abstract

Engineers play a critical role in the development and improvement of products and services as they follow the path from research to commercialization and success in the marketplace. To support these workplace roles, the engineering education enterprise often focuses on excellence in the two primary areas of research or education. In research, universities focus on discovering or inventing new discoveries as input to this process while in education, the focus is on educating engineering graduates in the general tools and skills necessary to operate and succeed in the technical workplace. The stage of innovation is distinctly different from research/invention and is often overlooked by educators as a critical stage in the commercialization path. This paper describes the role that an undergraduate engineering program can play in the critical innovation stage and suggests that a new scale of research, innovation, and education is appropriate for defining the mission of engineering universities.

Invention to Innovation and the University Role

In a business context, the term 'innovation' is applied broadly with a range of meanings including creativity and incremental to radical changes in an organization or processes[1,2,3] . In a technical context, the term has a more specific interpretation in the context of the processes of invention and innovation. Varieties of different models have been developed to describe the invention, innovation, and commercialization processes[4]. A simple linear model is shown in Figure 1 and it describes the steps from idea to introduction to the marketplace. The linear model suggests an orderly process moving forward from one stage to the next. Schoen et al.[4] propose a cyclic model as shown in Figure 2 and suggest that both the invention and innovation processes are far more chaotic and random in nature. In Figure 2, it is suggested that basic research leads to invention with a high percentage of these activities leading to a dead end. It further suggests that the innovation process acts upon inventions in a business context to further the development and progress toward commercialization.

The traditional scale to define the role of the university is a 'research' or 'education' scale as shown in Figure 3-a. Large universities with a research emphasis focus on the basic research and invention in engineering and the sciences. This work is performed by research faculty and graduate students and is often funded by government agencies or corporate sponsors. It is understood that it is an expensive and high-risk proposition and commercialization benefits may occur many years in the future if at all. These projects often end at the point of creation of intellectual property, patents, and perhaps a proof-of-concept prototype. It is often left to the private sector to identify the outcomes to be moved through the later innovation stages.

Universities without a research focus are often known for excellence in education to prepare graduates to go on to a career in industry or graduate school. Because the career paths of graduates span a wide range of academic, industry, or technical roles, the curriculum takes a 'just in case' approach and includes a broad overview of engineering tools and skills in a discipline. Many education-focused universities do include a component of hands-on project work and it is increasingly included to meet the requirements of accreditation. Although most engineers work in the innovation stages of development in their careers, real involvement in innovation and related projects is often believed to be beyond the capability of an undergraduate university and therefore left to the private sector.

Over 8 years of experience with the Rose-Hulman Ventures program has shown that an institution with a focus on undergraduate education in engineering, math, and science can play a meaningful and successful role in innovation stage projects with industrial partners. Therefore, the traditional categorization of engineering programs having either a linear 'research or education' focus may be expanded to include 'innovation' as a third dimension as shown in Figure 3-b.

A Program in Innovation Projects for Undergraduates

The Rose-Hulman Ventures program was started in 1999 with multiple missions including providing unique educational experiences for students and to have economic development impacts on Indiana based businesses[5]. The program has served as an incubator and technology center over the years of operation and has involved over 100 companies and 600 students working in internship roles. Today, the program operates on a year-round basis with ongoing project work with 18-20 companies involving 70 to 85 student interns and 20 staff/faculty. A unique feature of the program is that students work in co-curricular internship roles under the supervision of project managers allowing the program to take on more real and challenging projects from client companies. The internships are a 'for-pay', not 'for-credit' and students work part-time during the academic year and full-time during the summer months.

The program has two main goals of providing outstanding educational experiences to students as well as providing project results and value to the client companies. To achieve these goals, a realistic work environment as an 'engineering services' organization focusing on innovation stage projects has emerged as a successful program model. While not a professional services company, modeling the environment and culture in a realistic manner has proven to be successful for both students and clients companies.

Virtually all of the projects in the program are 'innovation stage' projects (as opposed to research focus) as depicted in Figure 1. The goals and objectives of client project work often includes the activities of design, modeling, prototyping, or testing which clearly fall in the innovation stage of advancing/enhancing a development toward commercialization and the marketplace. The program seeks a mix of projects from small and large companies across a range of industry segments.

Characteristics of appropriate projects often include those which:

- are important to the company and will have business impact,
- fit in the range of design, modeling, and testing,
- do not require specialized facilities or equipment,
- have resource constraints for getting it done, and
- have an exploratory component to it where the company can identify general desires, but does not have a detailed specification written.

During the years of operation of the RHV program, it has been recognized that the 'context' and realism of the project work is significantly different from a classroom project setting. Recently, the characteristics of classroom and workplace problems have been explored by Jonassen, et al.[6] with one conclusion that classroom problems often do not prepare graduates for the complexity and challenge of real workplace problems. It is further suggested that workplace problems have unique characteristics that are difficult to create in the classroom experience including:

- Ill-structured, high complexity and ambiguity,
- Multiple, often conflicting goals,
- Varied problem solving approaches,
- Success measured by 'client satisfaction' and rarely by engineering standards,
- Most constraints are non-engineering,
- Problem solving expertise is distributed among team members, and
- Unexpected problems occur during solution.

Through the structure of the RHV program and client agreements, most of the attributes of the workplace problems naturally occur during the course of project work. To the student interns, the program is structured as an on-campus internship position working on real problems for client companies. Students work in teams managed by a project manager and perform the majority of the technical work under the guidance of the project manager. Students sign a nondisclosure agreement, report to work in a separate facility dedicated to the Ventures program, report to a project manager supervisor, and track hours and work results. Since the project work is defined by the client company, the realism of the work environment and experience is high with a high level of engagement by both interns and client companies. Client expectations for progress and deliverables are significantly higher than a typical classroom or senior design project.

Results in Innovation Stage Projects

A variety of formal assessment activities have been performed over the years including student outcomes, client outcomes, economic development impact, and performance feedback between project manager and student. Results reported here focus mainly on student and client surveys and outcomes.

Student Benefits – A range of benefits are commonly reported by students who have participated in the program including:

- Enhanced classroom learning - students report that the real project work provides a better background and context to apply and relate classroom concepts,
- Professional skills experience – experience in teamwork, communication, and leadership which are the skills often desired by potential employers,
- Career planning - students report that the experience either confirms their selection of a major and interest area or they learn what career and technical path they do not want to pursue, and
- Internship experience – most important is that it provides 'professional experience' and is often the first opportunity that the student has to work as a technical professional. This is beneficial for demonstrating 'work experience' on the resume, securing the next internship, and is crucial for job hunting.

In addition to these general and anecdotal benefits, periodic assessment studies have been done. A simple, single measure metric tracked since 2002 is the senior survey score for the RHV program. In the spring of their graduating quarter, seniors are surveyed on a broad range of campus classroom, facility, and program activities, one of them being the RHV program. Students are asked to rate the quality of the program on a 1 to 5 scale where 1 indicates poor quality and 5 indicates excellent quality. Table 1 shows the senior survey score for the RHV program.

Year	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Senior Survey Score	3.43	3.95	4.06	4.07	4.12	4.29	4.20

Table 1 – Senior Survey Score for RHV Program

An increasing trend is seen with a score of 4.20/5.00 in the current year indicating a high overall level of student population awareness and satisfaction with the program.

In selected years, assessment activities have been carried out with students in the RHV program. A common question in all these surveys is '*Overall, how satisfied have you been with your RHV experience*' with five possible choices being very satisfied, satisfied, neither satisfied or dissatisfied, dissatisfied, or very dissatisfied. Table 2 below indicates the percentage of students answering 'very satisfied or satisfied' with their RHV experiences and the trend again indicates a high level of student's satisfaction with the program.

Year	***2001***	***2004***	***2006***	***2007***	***2008***
% Very Satisfied or Satisfied	91%	95%	100%	100%	91%

Table 2 – Student Satisfaction with RHV Program

In 2006, the assessment survey included a number of topics including comparisons to classroom experiences and learning outcomes. Students in the program were asked the following question - '*Overall, my experience in working with the Rose-Hulman Ventures project team was meaningfully different than my experience with working with a team of students on a class-related project.*' The majority of students (90%) reported their RHV project team experience was meaningfully different from their experience working in teams for class-related projects (60% strongly agree, 30% agree, 10% neither agree nor disagree).

A series of questions on learning outcomes, skills, and roles are completed by students. The first question is related to general learning outcomes for the program, '*For each of the learning outcomes below (Table 3), please indicate how well your Rose-Hulman Ventures project experience contributed to your development of that attribute'* and student responses are summarized in Table 3.

Student responses fall primarily in the 'moderate, well, and very well' categories indicating a broad range of educational impacts on students.

Outcome	***Not at All***	***Barely***	***Moderately***	***Well***	***Very Well***
A. Demonstrate knowledge of a professional code of ethics	10%	0	50	30	10
B. Evaluate the ethical dimensions of professional engineering, mathematical, and scientific practices	20	10	40	20	10
C. Demonstrate an awareness of how the problem is affected by social concerns and trends	10	5	35	30	20
D. Demonstrate an awareness of how the proposed solution(s) will affect culture and the environment	0	25	40	25	10
E. Share responsibilities and duties with other team members	5	0	20	30	45
F. Analyze ideas objectively to discern feasible solutions and then build consensus	0	0	10	35	55
G. Develop a strategy for action	0	0	5	55	40
H. Identify readers/audience, access their previous knowledge & information needs, and organize/design information to meet the needs	0	15	40	30	15
I. Provide content that is factually correct, supported with evidence, explained with sufficient detail, and properly documented	0	15	30	20	35
J. Test readers/audience response to determine how well ideas have been relayed	20	10	45	10	15
K. Submit work with a minimum of errors in spelling, punctuation, grammar, and usage	0	20	25	25	30%

Table 3 – Student Development of Educational Outcome Attributes

The next question relates to technical and professional skills learned in the program, '*Please indicate the 5 skills learned at Rose-Hulman Ventures that you feel will be the most useful in the upcoming academic year'* and student responses are summarized in Table 4.

It is interesting to note the top skills cited include technical skills but also include team skills, the impact of market and financial factors on engineering decisions, and life long learning. Several of these are items in the ABET 'a though k' learning outcomes.

Rank	***Skill***	***%***
1	Ability to design a product or process to satisfy a client's needs subject to constraint	90%
2	Ability to apply problem solving skills necessary for engineering practices	75%
3	Ability to work effectively in teams	65%
4	Understanding of the impact of marketing factors in engineering decisions	45%
5	Understanding of the impact of financial factors in engineering decisions	40%
6	Ability to recognize the need for life-long learning	35%
7	Understanding of the role of intellectual property in engineering decisions	30%
8	Ability to communicate effectively orally	30%
9	Ability to understand the impact of engineering solutions in global societies	20%
10	Ability to design experiments	20%
11	Ability to communicate effectively in technical writing	15%
12	Understanding of discipline specific contemporary issues	10%
13	Ability to conduct experiments	10%
14	Recognition of ethical and professional responsibility	5%
15	Other	5%
16	Ability to analyze data	5%
17	Ability to interpret data	0%

Table 4 – Student Ranking of Skills Learned

Finally, a question about different roles played during project work is asked. In Davis et al.[7], the concept of an 'engineer profile' is developed describing the skills and behaviors that an engineer needs to exhibit to be successful in the workplace. The roles identified in the engineer profile of leader, designer, collaborator, communicator, and self-grower are included in the question *'For each of the roles below (Table 5), please indicate how frequently you fulfilled each role during your Rose-Hulman Ventures experience.'*

	Never	Rarely	Occasionally	Often	Frequently
A. *Leader:* take initiative in guiding the project	0%	15	25	40	20
B. *Designer:* produce work products on time and within budget	0	0	5	50	45
C. *Collaborator:* contribute constructively to team performance	0	5	5	40	50
D. *Communicator:* communicate effectively with key stakeholders	0	0	30	25	40
E. *Self-Grower:* proactively learning and using resources	0	0	0	35	65%

Table 5 – Roles Fulfilled During RHV Project

Responses to the question indicate students often or frequently are able to experience and practice roles they will need to play in the workplace. One of the lower ranked roles is 'leader' and while seemingly surprising, with team-based projects, not all students experience team leader opportunities. Ways to increase and provide leadership opportunities to more students are being considered.

Table 6 has been constructed to link the attributes of workplace problems to the assessment results in Tables 3, 4, and 5. Each workplace problem attribute connects to at least one assessment outcome indicating the RHV experience provides a broad introduction to the characteristics of workplace problems for students.

Workplace Problem Attribute	***Table 3***	***Table 4***	***Table 5***
Ill-structured, high complexity and ambiguity	F, G	4, 5, 9	
Multiple, conflicting goals	C, D	1, 4, 5	
Varied problem solving approaches	F		B
Success measured by 'client satisfaction' and rarely by engineering standards		1	D
Constraints are non-engineering	B, C, D	4, 5	
Expertise is distributed among team members	E	3	C
Unexpected problems		6	A, E

Table 6 – Workplace Problem Attributes and Assessment Outcomes

The assessment results show a clear connection between educational outcomes reported by a high percentage of students and both Institute learning outcomes and the common characteristics of workplace problems.

<u>Client Benefits</u> – Since inception, the program has provided services to over 100 companies. The majority of these have been Indiana based companies and span a range of small to large across a broad range of industry segments. As an indication of impact and project quality, seven client companies have been recipients of Indiana 21st Century Fund awards which is a highly competitive economic development program supporting small business administered by the Indiana Economic Development Corporation.

Client companies have reported a number of benefits of the program including:

- expansion of their engineering capacity in a flexible and configurable way,
- ability to achieve results on important technical needs,
- ability to engage students in a flexible internship program to aid in screening prospective hires, and
- ability to achieve exposure and presence on campus.

In 2008, a client satisfaction survey was developed and administered by a professional marketing services firm (Walker Information, Indianapolis, IN). The survey received responses from 54 companies previously or currently served by the program. Significant results from this survey include:

- RHV creates positive business impact for companies. Virtually all companies (94%) said that RHV's work had an impact on their business, and over half (55%) said the impact was high or very high,

- RHV client companies tend to have positive experiences with the program – 83% report a very good or excellent experience.

- RHV achieves a customer loyalty score of 66% which exceed the norm (54%) for businesses of all types in the survey companies database.

- RHV achieves deliverables – over half of client companies reported they received a new product (57%), enhanced capabilities, and/or new product features.

FAST Diagnostics, a 21st Century Fund award winner, is an Indianapolis based company that turned to RHV for assistance with innovation-stage, product development work. The company is developing a reusable optical device with a single injectable fluorescent compound that will provide accurate and rapid measurement of the rate by which kidneys filter waste products from the bloodstream. This is the true glomerular filtration rate which is the primary indicator of injury and disease progression. There is presently no accurate and rapid method to diagnose acute kidney injury (AKI) and chronic kidney disease which affects 7 percent of all hospitalized patients with a mortality rate often exceeding 50 percent.

The original research and 'invention' was developed at the Indiana University School of Medicine and as a start-up company, FAST Diagnostics turned to RHV for assistance in developing a commercially viable prototype system. RHV has developed a medical instrumentation prototype combining optical, mechanical, and electrical technologies. Specific technical projects have included refining the optical subsytems layout, developing mechanical mountings, and designing the electrical system signal processing boards. Over the course of the project, nine undergraduates from five different majors, one faculty member, and two project managers worked on the technical team. FAST Diagnostics is currently progressing with technical and business development activities. This is clearly a case where the original discoveries and intellectual property came from a research university and the follow on innovation-stage development was needed to advance the technology down the path to commercialization and the marketplace.

Institute Benefits - A range of Institute level benefits have been observed and documented from the operation of the program. First, the over 300 internship experiences provided annually to provide professional experiences that provide a critical career services benefit to students during their job search activities. The program has also been valuable and a documented differentiator during the recruiting and admissions process. The program is one stop on campus-day visits by prospective students and parents. Of current freshmen who had heard of the program before enrolling, the program had an impact on their decision to attend for 50% of them.

The program also clearly has benefit for corporate partnerships and relationships. The program attracts some of the leading technology based companies in the region to the campus and generates over $1 million per year in revenue. Finally, the program is of benefit for defining the strategic role that a university with an undergraduate mission can play in 'innovation stage' projects and economic development often alongside much larger universities with a research focus. The program breaks the traditional 'research/education' mission for a university and creates a new scale for defining a mission and role in innovation (Figure 3-b) which is distinctly different from research yet unique, valuable, and complementary to a mission in undergraduate education.

Although a very successful operational model has been developed and the program provides a range of unique benefits to the Institute, challenges remain. These include:

- Demonstrating that the program is a complement not a competitor to the traditional activities of student education. This has been mitigated by faculty champions involved in the program who can demonstrate that their involvement has benefited both their teaching and scholarly accomplishments.

- Maintaining the balance between the multiple missions of providing tangible value to students, client companies, and the university.

- Developing a sustainable financial model for the program. As a program with both an educational, client services, and Institute level missions, the cost structure is high and capturing value from client projects and other funding sources is challenging.

Conclusions

Innovation stage projects play a key role in the commercialization of new and improved products and services but their importance is often overlooked in the educational setting. Experience with the Rose-Hulman Ventures program has shown that an institution with a focus on undergraduate education in engineering, math, and science can play a meaningful and successful role in innovation stage projects with industrial partners. These projects provide a number of documented benefits to students, the client partner companies, and to the mission of the university as a whole. It is suggested that the traditional 'research vs. education' scale to define the mission of engineering programs be expanded to include a third dimension of innovation.

Biographical Information

Dr. William A. (Bill) Kline holds a joint appointment as Associate Dean for Professional Experiences and Associate Professor of Engineering Management at Rose-Hulman Institute of Technology. As Associate Dean, he is director of Rose-Hulman Ventures, a program of Rose-Hulman, providing educational opportunities for students and faculty through project work with technology-driven businesses. He holds a Ph.D. degree in Mechanical Engineering from the University of Illinois at Urbana Champaign. Bill teaches courses in design, systems engineering, manufacturing systems, and quality management. Prior to joining Rose-Hulman, he worked in an entrepreneurial and technical management role in a machine monitoring company. Email at kline@rose-hulman.edu.

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Stage	Idea	Research	Product and Market Concept	Product Development	Product Launch	Business Scale-up
Staff	Inventor	Scientist	Engineer/Business	Engineer/Techncian	Engineer/Techncian	All Fields
Activities	New idea or vision.	Develop and test new scientific results, new inventions, proven technology, and intellectual property.	Develop product concepts and test market feasibility, evaluate technical and market risks.	Develop working prototypes for concepts, refine, and finalize product.	Develop manufacturing processes and scale up, cost analysis.	Develop engineering, manufacturing, and business support systems. Growth and economic impact.

Innovation Stages

Figure 1 – Linear Invention to Innovation Model

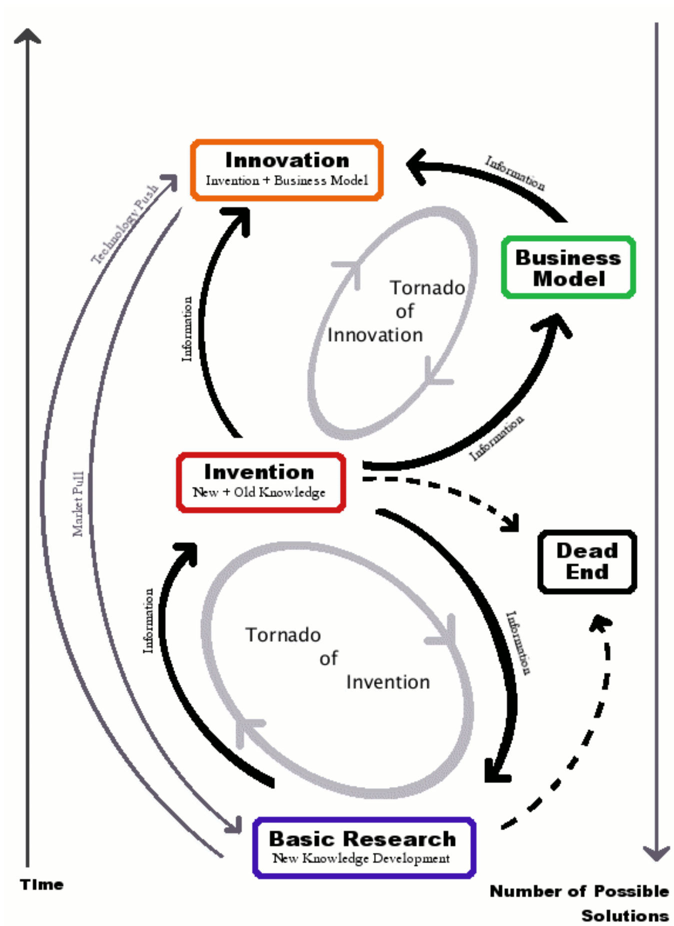

Figure 2 – Schoen et al.[4] Innovation Cycle Model

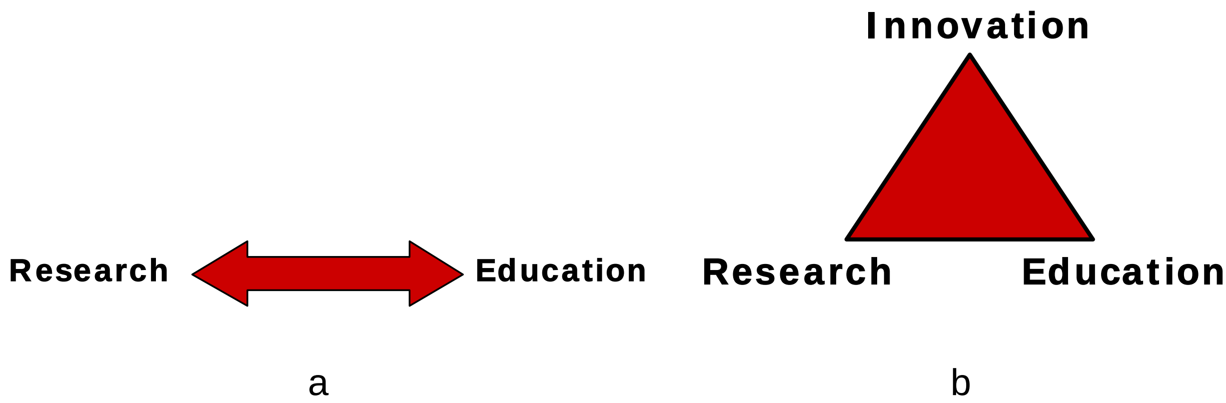

Figure 3 – University Missions in Research, Education, and Innovation