Integrating Practice into Engineering Education

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Abstract – Academicians have noted a deficiency in engineering education offered by colleges and universities. The deficiency is that a majority of engineering graduates are taught by engineering faculty with little or no industry experience. Faculty far removed from advances in industrial practice will miss important opportunities to tailor the curriculum to crucial industrial needs. This will be to the disadvantage of their students. Regardless, employers yet expect colleges and universities to provide specifically trained graduates or graduates that have familiarity with the role of engineering in industry. West Point has been successful in bridging this gap while dealing with unique constraints not found at most academic institutions.

The purpose of this study is to describe a department's approach at incorporating elements of engineering practice into its' engineering curriculum. A survey was administered to graduating seniors to conduct an assessment of this approach. Graduates provided positive feedback on the course's effectiveness and offered suggestions for updating its' organization and structure. The results of the survey, from quantitative and qualitative responses, are used to assess the relevancy of this approach.

1.0 Introduction

What we have traditionally learned from history is that we generally do not learn from history. The deficiencies present in American schools and colleges are not new and unusual. They have been around for awhile and have led to the same outcomes or problems facing America's economy today – an uneducated workforce. Over twenty years ago reformers became increasingly preoccupied with the effects of inadequate education of United States workers on the nation's economy. This development coincided with increasingly competitive economic challenges from Japan, Germany, and other European countries. Although global economic competitiveness is built upon the foundation of both an educated and skilled workforce, a skilled workforce is built upon the foundation of an educated workforce. A well-rounded education is necessary to produce workers, which allow the United States to compete successfully with other countries. No nation can grow, economically or socially, without significant and sustained investments in the knowledge and skills of its people.[1]

In an analysis of the education systems of America's competitors, reformers noted that the workplace played a crucial role in the education system of Germany and Japan. John Dewey, who is considered the father of education, strongly felt that the educator had to narrow the distance between the classroom and the world outside it.[3] In the United States, too much time elapsed before high school graduates got a chance to use whatever advanced skills they might have learned in school.[1] The same can be said for some college graduates. Wherever education is inadequate:[1]

- Students know little about work.
- Students have no clear idea about what they must do to enter a particular career or occupation.
- Students do not know what might be expected of them at work since the teaching environment bears little to no resemblance to the engineering environment found in industrial companies.
- Schools do not teach the attitudes and maturity needed on the job.
- Schools isolate young people from adults who could act as models and mentors.
- Schools do a poor job of teaching the so-called advanced generic skills or workplace basics such as problem solving and teamwork, and the job-specific skills that are taught atrophy as young people spend a few years churning through unskilled youth jobs.
- Schools provide a form of schooling that is ineffective in its pedagogic strategy.

In light of these findings, academicians have noted a recent deficiency in engineering education offered by colleges and universities. The deficiency is that a majority of engineering graduates are taught by engineering faculty with little or no industry experience. Faculty far removed from advances in industrial practice will miss important opportunities to tailor the curriculum to crucial industrial needs.[6] This will be to the disadvantage of their students. Regardless, employers yet expect colleges and universities to provide specifically trained graduates or graduates that have familiarity with the engineering side of the business world.[9] West Point has been successful in bridging this gap while dealing with unique constraints not found at most academic institutions.

High schools, college and universities strive to effectively prepare graduates for the environments in which they are about to enter; however they sometimes fall short. The age-old solution is to introduce students to industry practices by simply allowing students to work directly in industry settings. Not only has this concept been practiced and proven in Europe and abroad, but also in the United States in reaching the goals outlined in a work-based education program. Another effective option is to integrate practice into the educational curriculum of colleges and universities. The School-to-Work Opportunities Act of 1994 has satisfied both alternatives, particularly for high schools but the concept may be extended to colleges and universities. This act calls for a comprehensive reform work-based plan that includes school-based learning, work-based learning, and connecting activities. The third component, connecting activities, includes matching students with appropriate work-based learning opportunities and providing a school site mentor to act as liaison between the employer (or sponsor organization) and the student's school, teacher, social administrator, and parent. A further activity is to provide technical assistance to employers in designing school-based learning components.[1]

One particular example of a connecting activity is the United States Military Academy (USMA) capstone course that exist primarily within engineering disciplines. Although the School-to-Work Opportunities Act of 1994 applies directly to high schools, the concept has been modeled and tailored it to a university setting. The capstone course is the academy's connecting activity for senior cadets and provides the basis for maintaining the link between the workplace and the classroom. The course offers cadets an opportunity to apply a three-year comprehensive set of skills and concepts learned in the classroom to an industry related project. Academic liaisons work with industry to develop problem topics of relevance to the Army and the Academy, while ensuring projects are scoped to capabilities of project teams.

The purpose of this paper is to introduce and describe one department's, at USMA, attempt at incorporating elements of engineering practice into its' engineering curriculum. That department is the Department of Systems Engineering (DSE). Assessment of the capstone course by those who have participated in the course is essential to ensure that the course is producing engineering graduates that meet the demands of a rapidly changing technological and work environment. The assessment discussed in this paper was achieved by surveying 2004 graduating seniors. Seniors provided positive feedback on the course's effectiveness and also offered suggestions for updating its' organization and structure.

The paper begins with background information of USMA's academic program followed by a brief description of the capstone course. A description of the survey and its methodology follow. Next, survey results are highlighted and analyzed. Conclusions and acknowledgments follow.

2.0 USMA's Academic Program

The academic program at USMA has evolved in response to the needs of the Army and trends in higher education. USMA's balanced offering of courses in the arts and sciences leads to a Bachelor of Science degree for all cadets and builds a solid foundation for future graduate study. The core curriculum incorporates 26 courses equally balanced between the arts and sciences; it provides the foundation for the academic program and the broad knowledge necessary for achieving success as a commissioned military officer. There are currently 65 optional majors and 68 fields of study. They cover virtually all the liberal arts, science and engineering disciplines one would expect to find in highly selective colleges and universities. More than 75 percent of all cadets elect a major whereas others elect a field of study. Cadets electing to take less than the prescribed number of courses required for majors may enroll under the field of study program. Since USMA requires all cadets to graduate with a Bachelor of Science degree, non-engineering majors must take three engineering courses in an engineering discipline of their choice. These cadets are referred to as a "Sequencer."

3.0 USMA's Capstone Course

Although cadets at West Point are taught primarily by engineering faculty that have no experience within industry, we strive to expose cadets to engineering practices within industry. We achieve this through our annual capstone course. The capstone course at USMA is the academy's connecting activity for senior cadets and provides the basis for maintaining the link between the workplace and the classroom. The capstone course requires students to apply their comprehensive set of skills and concepts to a real-world problem for a real-world project, or to a specific research area. The actual projects themselves combine elements of systems engineering, information systems engineering, engineering management, and operations research theory and practice, allowing students to conduct design and experimental work for clients along the lines of actual practicing systems engineers and other professionals. The projects are selected based on appropriateness of the topic, potential student and/or faculty interest, and project scope. The clients for these groups develop a relationship that is designed to mirror the relationship of a consulting group working with a client. Clients receive interim reports, a final report, and a presentation from the group. For the students, their presentation marks the culmination of their academic careers and affords them the opportunity to present their findings to their faculty mentor, their client, a general audience, and a panel of experts in the field.

For cadets who choose to study a major in DSE, the capstone course spans both semesters of their senior year. Typically, the first semester is devoted to developing a thorough understanding of the clients' objectives for the systems and the current state of the system. During the second semester, cadets complete the Systems Engineering Management Process (a problem-solving approach) as it applies to their project, sometimes focusing on a specific area (modeling and analysis or cost vs. value analysis) as the client desires. For cadets who are fields of study or sequencers within DSE, their projects are smaller in scale (comparable to acquired skills) and only occur second semester of their senior year.

4.0 Survey

The objective of the capstone course is to allow seniors an opportunity to bridge the intellectual gap between skills learned in the classroom and their application in industry. Additionally, seniors have the opportunity to interact with adults who could act as models and mentors. The purpose of the survey was to obtain feedback from graduating seniors on the effectiveness of the capstone course in achieving that objective. A specific objective was to assess strengths and weaknesses of the capstone Course.

The survey responses were divided into three groups - majors and non-majors. The majors are Systems Engineering, Information Systems Engineering, Engineering Management and Operations Research cadets. The non-majors are Systems Engineering Field of Study and Systems Engineering Sequencer cadets. One hundred three cadets participated in the survey. Thirty-one were majors, seventeen were fields of study, and fifty-five were sequencers. One set of survey questions was developed and administered to all cadets. Questions were both qualitative and quantitative and were formulated with the help of USMA faculty members in DSE. The questionnaire includes items representing measures of project relatedness to discipline, client interaction, use of learned tools, use of new tools, confidence in ability to learn new tools, industry application, discipline support, strengths and weaknesses of capstone course, and recommendations for improvement. The questions are shown in Table 1.

Table 1. Survey Questions

Qualitative Assessment

1. What is your major?
2. What is the name of your capstone project?
3. Did your project span 1 or 2 semesters?
4. Which of the following describes your project? **(Circle one or more)**
   a. Curriculum-based industrial design project
   b. Cross functional design team that may include non-engineering team members
   c. National competitions (SAE challenges, DOE challenges, etc.)
   d. Decision Analysis
   e. Optimization
   f. Project Management
   g. Process Modeling & Analysis
   h. Modeling & Simulation
   i. Statistical Analysis and Stochastic Processes
   j. Operations Management
   k. Other: ______________________________
5. Who was your project client?
6. What was the objective of your capstone project?
7. Which portion(s) of the capstone project did you find rewarding? **(Circle one or more)**
   a. In Progress Reviews
   b. Client Decision Brief
   c. Log Book/Smart Book
   d. Preparation of Project Report
   e. Systems Engineering Management Process
   f. Interaction with Client
   g. Academic challenge presented by the project
   h. Techniques and Tools used in the project
   i. Interaction with advisor
   j. Organization of Capstone course
   k. Other: ______________________________
8. Which portion(s) of the capstone project did you find lacking? **(Circle one or more)**

- Available resources **(please explain)**
- Guidance **(please explain)**
- Objective
- Other **(please list)**

9. How should the capstone program evolve in future years?

Quantitative Assessment

1. How much interaction, on average, did you have with your client? **(Circle one)**

1	2	3	4
Daily	Weekly	Monthly	Other? ___________

2. What techniques (simulation) and tools (e.g. PROMODEL) did you use in your capstone project that were part of your academic program?

1	2
None	Some

3. What new techniques or tools did you learn on your project that was NOT part of your academic program?

1	2
None	Some

4. How confident are you that you can learn new techniques and tools in the future?

1	2	3	4	5
Very Low	Low	Neutral	High	Very High

5. How well did the capstone project fulfill the purpose it was created for – *to present cadets the opportunity to discover the real world applicability of their academic endeavors*?

1	2	3	4	5
Poor	Bad	Neutral	Good	Excellent

6. How well did the capstone project support your major and provide you an opportunity to apply systems engineering, engineering management, information systems engineering, and/or operations research principles to your project?

1	2	3	4	5
Not At All	Somewhat	Neutral	Very Much	Completely

4.1 Survey Methodology

The instrument employed in the survey consists of 4 qualitative items, which measure course strengths and weaknesses, and recommendations for improvement; and 6 quantitative items, which measure client interaction, application of learned and new tools, confidence in ability to learn new tools, industry application, and discipline support. Three population groups were included in the survey: 1) majors; 2) sequencers; and 3) field of study cadets. To protect respondents' confidentiality, respondents were asked to identify themselves by discipline.

4.2 Survey Results

Overall, the majors in our programs were generally satisfied with the capstone course, whereas those designated as field of study or sequencers were not as satisfied. A discussion of the results follows.

4.2.1 Course Strengths

The capstone course combines many different methods of education and when asked which portions of the course were the most beneficial, each portion was mentioned at least once by majors, less frequent by sequencers and much less frequent by field of study cadets. The majors found the following portions rewarding (as rated by at least 25% of all respondents):

- Interaction with Client
- Interaction with Advisor
- Techniques and Tools used in the project
- Client Decision Brief
- In Progress Reviews
- Systems Engineering Management Process
- Academic challenge presented by the project

The sequencers found the following portions rewarding (as rated by at least 25% of all sequencer respondents):

- ***"Nothing"***
- Techniques and Tools used in the project

The field of study cadets found the following portions rewarding (as rated by at least 25% of all field of study respondents):

- ***"Nothing"***
- Interaction with Client

Based on the findings, sequencers and field of study cadets do not receive much from the capstone program. This distinction may be due to the fact that majors work with clients and organizations external to USMA while sequencers and field of study cadets primarily work with internal USMA organizations that in most cases provide the same project annually. The reason is not fully clear; however the answer may be found in recommendations sequencers and field of study cadets provide to improve the course.

4.2.2 Course Weaknesses

Building on the previous question, the respondents were asked which portion of the capstone course was lacking. This question was mistakenly excluded on the survey administered to sequencers and field of study cadets. Data was collected only for majors. Majors rated *"Lack of communication with client"* and *"Need for multi-disciplined teams"* among the highest while *"More time," "Lack of data,"* and *"Objective"* rated among the lowest.

4.2.3 Recommendations for Improvement

As stated, sequencers and field of study cadets do not receive much from the capstone course. Their recommendations for the course are of greater interest since the responses of majors indicate they are generally pleased with the course. Although sequencers do not receive much from the course, their primary recommendation was that *"Nothing should be done to change the course (structure)."* Two additional recommendations provided by sequencers were 1) *"Use real-world projects from external organizations"* and 2) *"Increase instructor involvement."* Field of study cadets' primary recommendation was *"Use real-world projects from external organizations."* Majors, on the other hand, primarily recommended *"Increase project duration to two semesters."*

Several themes were mentioned jointly by majors, sequencers and field of study cadets. They are 1) *"Nothing should be done to change the course (structure),"* 2) *"Use real-world projects from external organizations,"* 3) *"Increase project duration to two semesters,"* and 4) *"Increase client involvement."* These themes were chosen by 10% or more of all survey participants. In summary, the capstone course may be enhanced by increasing the pool of external projects as well as encouraging client interaction throughout the course.

4.2.4 Client Interaction

Work-based education involves exposing students to real work but it entails more than simply providing them with work experience. Students isolated with their peers in school have little contact with adults other than the school staff and faculty. Exposing students to adults from industry who could act as models and mentors enables students to learn the attitudes and maturity needed in industry. The level of client interaction among the three population groups is depicted in Figure 1.

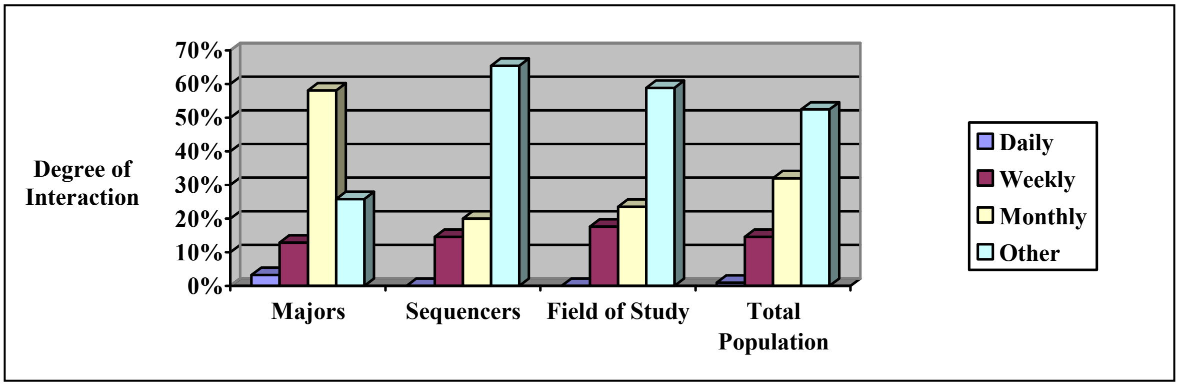

Figure 1. Level of Client Interaction

The category "Other" is defined by a time span of rarely to bi-weekly. For the total population, there was no consistent pattern when cadets would interact with clients; however cadets did interact occasionally during the course of the project. The results correlate with a primary recommendation offered by all cadets, which is to *"Increase client involvement."* Significant differences, if any, between populations may be noted using the Kruskal Wallis (K-W) Test.[10] The K-W test is a nonparametric test designed for ordinal type data and tells whether there are significant differences between opinions expressed among several populations. The test is an alternative nonparametric procedure to the *F* test for testing the equality of means in the one-factor analysis of variance when the experimenter wishes to avoid the assumption that the samples were selected from normal populations. The K-W test, at a significance level of $\alpha = 0.05$, shows that there is at least one difference among the three populations.

4.2.5 Application of Learned Tools, New Tools and Confidence in Ability to Learn New Tools

There are cognitive benefits directly associated with work-based education. Problem solving, teamwork, learning in context, and active participation of students in their own learning occurs when students get a chance to learn and use skills in a well-designed work experience. By incorporating education into real-world situations in which what is being learned will be used, work-based education bridges the cognitive gap between school and work. Additionally, work-based education motivates students by showing them how skills are used in real-world settings and how their success can depend on learning particular skills. An assessment of "Application of Learned Tools," "Application of New Tools", and "Confidence in Learning New Tools" are shown in Figures 2, 3, and 4 respectively.

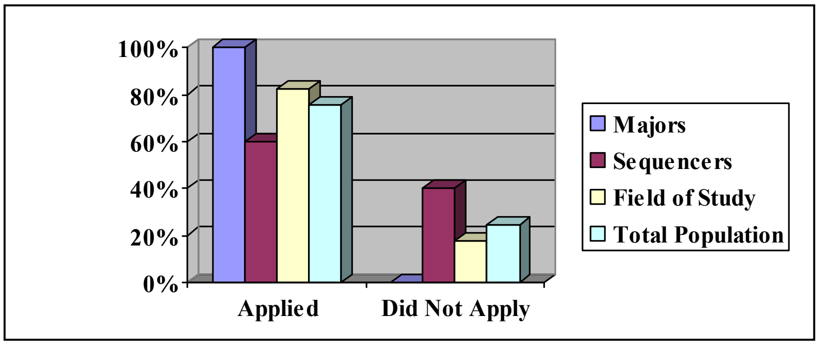

Figure 2. Application of Learned Tools

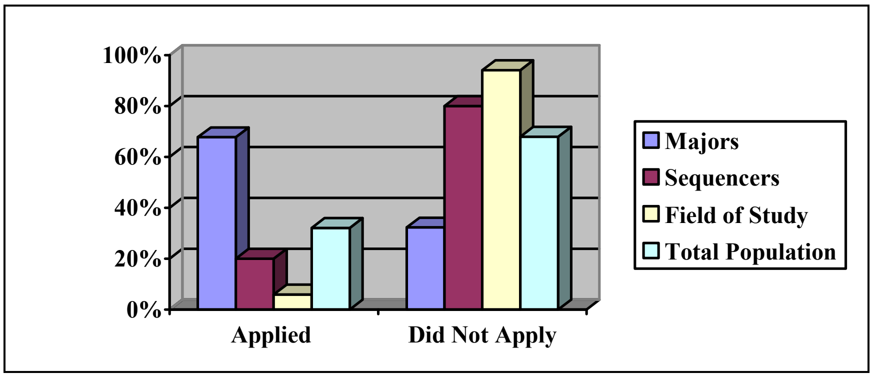

Figure 3. Application of New Tools

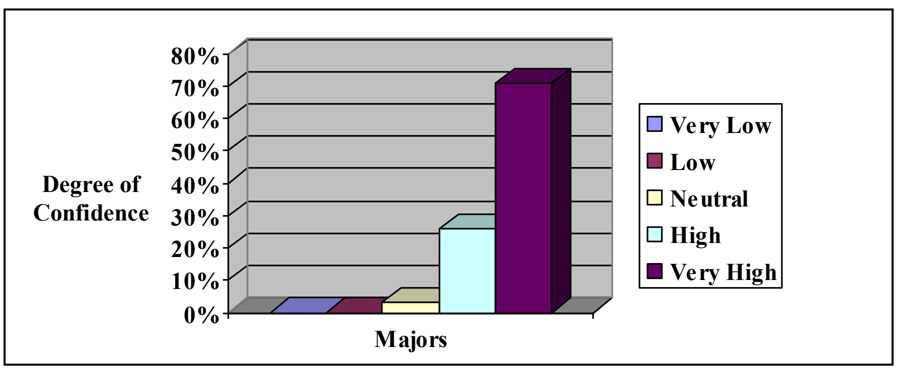

Figure 4. Confidence in Learning New Tools

The results indicate that approximately 45% of sequencers are not applying learned skills and that a majority of sequencers and field of study cadets are not challenged to learn new skills and concepts. This, perhaps, is another reason why at least 25% of sequencers and field of study cadets do not find the capstone course rewarding. The K-W test, when conducted for Figure 3 and Figure 4, show that at a significance level of $\alpha = 0.05$ there is also at least one difference among the three populations.

4.2.6 Industrial Application

Next, we measured whether students realized the application of their academic pursuits to industry. John Wayne Airport, Construction Engineering Research Laboratories, Department of the Army G-3 Prioritization Office, and American International Group are examples of client organizations that presented projects for cadets to work on. Additional examples are shown in Table 2. We expected each project to provide an opportunity for cadets to apply and extend concepts learned in the classroom and to use skills to accomplish something concrete. The results are shown in Figure 5.

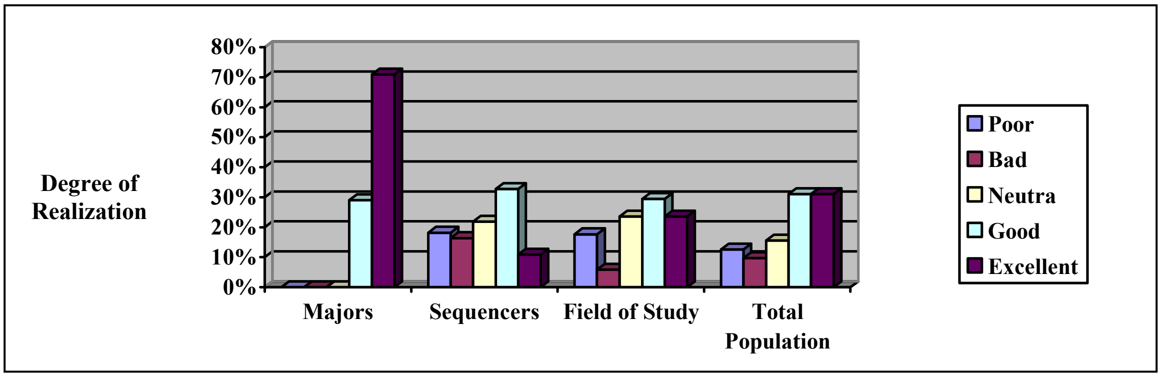

Figure 5. Industrial Application

The results show that majors generally realize the application of their skills in industry; however approximately 56% of sequencers and 46% of field of study cadets see no relationship between skills learned in the classroom and their application to industry. This is assumed to be due to the varying nature of projects majors are given and projects for sequencers and field of study cadets. The K-W test, at a significance level of, $\alpha = 0.05$ shows that there is at least one difference among the three populations.

4.2.7 Curriculum Support

Work-based education must include a well planned program of industry work that is coordinated with learning that has occurred in the classroom. The capstone course must include matching students with the right project in which their skills may be applied. Unless the work experience is relevant to what is being learned in the classroom, the intellectual bridge between the classroom and work will not exist. The experience must enhance, not undermine classroom learning. Building on the previous question, the respondents were asked how well their project related to their program of study. The question essentially assesses the degree to which projects or work supported a student's discipline. The results, shown in Figure 6, provide insight on whether we are inappropriately matching cadets to projects.

Table 2. Examples of Capstone Projects

Project Name	Team Discipline	Project Description	Client
Distributed Sensor Networks (DSNs)	Systems Engineering Information Systems Engineering Operations Research Engineering Management (Electrical Engineering) Engineering Management (Environmental Engr)	Investigate planning, placement, command, and monitoring issues related to DSNs.	Research Development and Engineering Command, Communications-Electronic Research, Development, and Engineering Center and Army Research Lab
Systems Modeling & Analysis of Retread Supply Chain Operations	Information Systems Engineering Operations Research Engineering Management (Civil Engineering) Engineering Management (Nuclear Engineering)	An investigation into reshaping supply chain operations in a major logistic system that parallels both US Army supply and distribution networks and conceptual modeling constructs for Network Centric Operations knowledge management networks.	Tire Centers, Inc.
Hypersonic Flight Capability & Its Use to Meet Army Missions & Threats	Systems Engineering Engineering Management (Civil Engineering) Engineering Management (Mechanical Engineering)	We will evaluate the military potential of the emerging new scramjet technology by envisioning new babble units and computing the value added for different threats including cruise missile defense.	Aviation & Missile Research, Development, and Engineering Center /Science Applications International Corporation/BAE Systems
Mini-Baja	Mechanical Engineering Engineering Management	The Society of Automotive Engineers competition is a regional competition that simulates real-world engineering design projects and their related challenges. Engineering students from over 50 colleges are tasked to design and build an off-road vehicle that will survive the severe punishment of rough terrain and water. Teams compete against one another to have their design accepted for manufacture by a fictitious firm. Students must function as a team to not only design, build, test, promote, and race a vehicle within the limits of the rules, but also to generate financial support their project and manage their educational priorities.	Society of Automotive Engineers
Transportation Safety and Risk Assessment	Systems Engineering Operations Research Engineering Management (Environmental Engr)	Develop a standardized means to quantitatively assess the quality of transportation safety programs to help users identify the key areas in which to focus efforts for improvement.	American Int'l Group and the US Army Safety Center

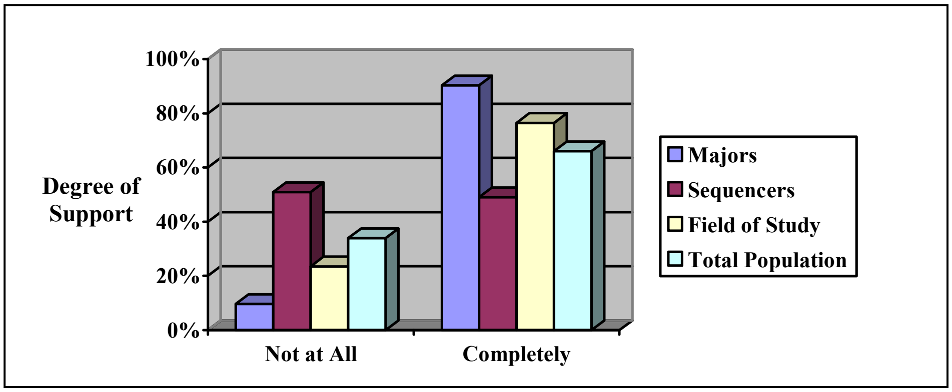

Figure 6. Curriculum Support

Majors and field of study cadets generally found that projects matched or challenged what they had learned in the classroom; whereas approximately 50% of sequencers did not. Based on responses provided by sequencers, it is assumed that projects chosen for sequencers do not challenge their potential. Projects must be better scoped for this population group. The K-W test, at a significance level of $\alpha = 0.05$, shows that there is at least one difference among the three populations.

5.0 Conclusion

Proponents of contextual learning argue that individuals learn skills more effectively if what they learn has a close relationship with their everyday activities. Others suggest that the learning environment needs to reproduce "the technological, social, time, and motivational characteristics of the real work situations in which what is being learned will be used".[1] Proper management of a course that integrates practice into engineering education is valuable to schools, students, companies, and the military and should offer students a unique, work-related educational experience that cannot be attained via a classroom experience alone; however there are a few key ingredients that should exist. First, the work experience must relate to the curriculum and school courses must be relevant to the world of work. Second, the concept must be adaptable to changes occurring in the workplace. The demands of a technology-infused business world change as rapidly as technology and it is therefore necessary that a work-based education course be adaptable in order to meet the changing demands within industry.

A number of refinements may be acted on to ensure that the objective of the capstone course is met for all cadets. First, the library of projects must include robust and challenging industry-related projects. Second, client involvement should be encouraged. Third, a concerted effort must be made to ensure cadets are matched to the right project. As these enhancements are instituted, there exists a greater chance that the capstone course will broaden cadet perspectives and provide all cadets with practical advanced education related to their professional responsibilities as future commissioned officers. An assessment of how well employers think graduating seniors are prepared to enter the workforce is an area of future research.

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References

1. Bailey, Thomas R., ed. 1995. *Learning to Work: Employer Involvement in School-to-Work Transition Programs.* Washington, D.C.: The Brookings Institution.

2. Barella, Elise M. and Keith W. Buffinton. 2004. Corporate Assessment of Strategic Issues in Technology and Management Education. *Proceedings of the 2004 American Society for Engieering Education Annual Conference & Exposition held in Salt Lake City, UT 19-24 June 2004.* ASEE.

3. Handlin, Oscar. 1959. *John Dewey's Challenge to Education: Historical Perspectives on the Cultural Context*. New York: Harper & Brothers.

4. National Research Council. 1985. *Engineering Education and Practice in the United States: Engineering Employment Characteristics*. Washington, D.C.: National Academy Press.

5. National Research Council. 1985. *Engineering Education and Practice in the United States: Engineering in Society*. Washington, D.C.: National Academy Press.

6. National Research Council. 1986. *Engineering Education and Practice in the United States: Engineering Undergraduate Education.* Washington, D.C.: National Academy Press.

7. Nothdurft, William E. 1989. *Schoolworks: Reinventing Public Schools to Create the Workforce of the Future*. Washington, D.C.: The Brookings Institution.

8. Powell, Robert A. and Curtis D. Tait. 2004. Developing Engineers in the 21st Century – An Integrative Experience. *Proceedings of the 2004 Integrating Practice into Engineering Education held in Dearborn, Michigan 3-5 October 2004*. University of Michigan-Dearborn.

9. Shepard, Sheri D. 2003. Design as Cornerstone and Capstone*. Mechanical Engineering Magazine*, 30 January.

10. Walpole, Ronald E. and Raymond H. Myers. 1985. *Probability and Statistics for Engineers and Scientists.* 3d ed. New York: MacMillan Publishing Co.

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