Engineering Education through Degree-Long Project Experience

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Abstract **- A new pedagogical approach called *engineering education through degree-long project* has been implemented in the mechanical engineering program at the University of Cincinnati as a part of the NSF CCLI project. The approach integrates selected courses in the undergraduate curriculum using a degree-long project as the theme. Design of Formula SAE® race car was employed as the first degree-long project. In each selected course, the concept of the approach and the role of the assignment relative to the degree-long project are explained as a part of the assignment. In early-year courses, assignments are simple problems designed to show how abstract concepts are eventually applied to engineering tasks to motivate students. In later-year courses, more involved assignments such as design projects of the suspension system and the driveline are given, which aims at nurturing creativity and ability to solve open-ended engineering problems. Assessment of student surveys showed that responses were more positive in later-year courses. The most difficult part of the approach was developing interesting and challenging problems yet relevant to practical applications in early-year courses which can be more benefitted from the approach. A strategy developed to improve the proposed approach is discussed.**

INTRODUCTION

Historically, engineering curricula have been largely developed based on engineering science model [1] that relies on a very structured curriculum. Early fundamental courses such as calculus and physics form the basis of follow-on engineering courses. Many engineering students in the early stage often do not see how the seemingly abstract math and science concepts taught in fundamental courses are related to engineering applications. As the result, some students lose interest in engineering, ending up quitting or wasting valuable time crucial to their education. The concept of cornerstone design courses that introduce design projects in the first year [2,3], has emerged out of the need to better engage students in the first two years with engineering faculty and engineering content. Even after the first two years, students feel an "impedance mismatch" across the courses because the curriculum is traditionally developed from the perspective of instructors, not from that of students. Another problem is that engineering students graduate with mostly domain-based knowledge, but not enough training to solve real-world, practical problems. This results in lack of the ability to apply theory to practice, a common complaint from industry, the major customer of engineering education [4]. Modern engineers need to be not only experts in their domain but also good communicators, team members and life-time learners [5]. The capstone (design) course has become an important part of the standard engineering curriculum to address these problems with strong thrust by ABET [6-9].

At UC, Design Clinic has been implemented as the senior capstone design course for the past twenty years. In Design Clinic, about 25 projects per year on average are sponsored by industrial companies who provide nominal financial support and technical guidance [10]. Design Clinic has been emphasizing students to learn how to synthesize disciplinary knowledge to satisfy engineering needs. Students learn how to define the problem, and cope with social, ethical, economic, safety and marketing requirements. While the program has been conducted successfully, the main challenge has been developing realistic problems relevant to engineering contents.

In most US engineering schools, the first two years of the curriculum are primarily devoted to basic science and fundamental engineering courses [11]. Cornerstone courses target improving student interest in forthcoming engineering courses and enhancing student retention [2, 12]. Through cornerstone design course, first year engineering students are exposed to engineering topics and engaged with engineering faculty whom they would not see otherwise. At the mechanical engineering (ME) program of the University of Cincinnati (UC-ME), "Introduction to Mechanical Engineering I, II, III" courses have been implemented as a three-quarter sequence to engage students with ME faculty and assign cornerstone projects.

Despite recent emphasis on PBL (problem-based learning), engineering curriculums still largely rely on a structured engineering science model. While the essence of the model is still necessary, there should be measures to reflect highly diverse educational needs constantly evolving from interdisciplinary technological needs of modern industry. Participations by other stakeholders, namely students and industry, are highly desirable in the curriculum development, which was one of the aims of the proposed concept. Garnering faculty supports, essential to make PBL programs successful, has been one of major difficulties [13]. Often PBL is considered as the task of "design" or "education" faculty but not that of "research" faculty. Effective implementation of cornerstone courses requires so-called "non-design" faculty to actively participate in the concept, which can increase their load beyond what they are normally accustomed to. As it is not practical to expect faculty all members to volunteer their efforts to the pedagogical need [14], it is necessary to design PLB programs to provide enough incentives to instructors.

The new paradigm, *engineering education through degree-long project experience* was designed to improve the current engineering curriculum at UC-ME as an ultimate PBL paradigm. The approach attempts to integrate courses across the entire curriculum around a theme of a degree-long project, ranging from fundamental science and cornerstone courses to the capstone design course.

DESIGN OF THE FIRST DEGREE-LONG PROJECT

Engineering curriculum has to be engaging and flexible while highly structured. *Engineering education through degree-long projects* was proposed to find a solution to this seemingly conflicting requirement. The followings are the issues found in typical current engineering curriculums, which have motivated the authors to develop the new paradigm.

- Fundamental math and science courses offered in early-year courses are often taught in a manner decoupled from other engineering courses. Concepts and principles are introduced without properly explaining how they will be used and what their practical implications are. Many first year engineering students often get frustrated by this and perceive that *engineering* is not what they have envisioned.
- Students do not have an opportunity to have an overall perspective of the entire curriculum. They do not have good understanding how various courses are related across the curriculum. Students simply follow individual courses without having a sense of direction. This is especially true in early years.
- Capstone design projects are not always designed in a way relevant to the courses taught in prior years. Often the project is conducted independent of the other courses in the curriculum. Quality of the capstone project varies widely depending on the source of the project (i.e., industry or faculty) and the instructor's background.
- In courses besides the capstone design course, emphasis is not insufficiently put on equipping students with ability to handle open-ended engineering problems. Many students are unprepared to handle unexpected situations and to stay focused through a multi-faceted long-term project.
- A typical engineering faculty does not have proper training to develop good PBL projects because he or she was, in many cases, educated in predominantly domain-knowledge oriented education system and does not have industry experience.

The new approach, engineering education through degree-long project experience, has been devised to provide a solution to the issues mentioned above. The approach attempts to integrate selected courses across the ME curriculum around themes of a few well-developed engineering design projects highly relevant to practical applications as well as the courses. Design of a Formula SAE® (FSAE) competition race car was chosen as the theme of the first degree-long project. One or two courses per year were identified based on their relevance to the theme and logistic constraints. In the courses offered during the first two-years, simple yet meaningful example problems or projects were developed to relate the course materials with the theme of the degree-long project. In these courses, the focus is on motivating students to learn fundamental concepts. In the courses taught in upper years, more complex and comprehensive projects were designed and employed. It was emphasized to maintain relevance of the projects to the theme project. The degree-long project experience culminates as the capstone design project in the senior year. The emphasis starts from motivating students, gradually changes to relating various core courses to the theme of the project, finally to developing flexibility and creativity to conduct realistic open-ended projects.

The Formula SAE® theme was selected because the topic is ideal to develop a degree-long PBL sequence for ME students. Because of the nature of the project, many ME courses could be easily integrated. The FSAE competition is a student driven activity where team members conceive, design and fabricate a small formula-style race car for the SAE international competition. Therefore, it is one big advantage that actual race cars built by the FSAE team are available to students as the hardware prototype for their project. For example, students often take measurements to estimate necessary data, and consult with the FSAE team members to get necessary answers to their questions. Furthermore, this ends up providing a side benefit of developing peer mentoring relationship amongst graduate students, upper year and lower year undergraduate students. The courses selected to develop this first degree-long project sequence and the assignments or projects implemented in the courses are explained as follows. It is noted that UC engineering programs are 5-year, quarter system program with mandatory coop requirement, which therefore the degree-long project program is planned based on.

First Year Courses

Calculus II (Being implemented in winter quarter 2010 through "Introduction to ME II", a course taught during the second quarter of freshmen year)

Differentiation by the chain rule: Needs for implicit differentiation and change of variables in executing differentiations are explained using an example of motion analysis of the vehicle. The procedure to execute the differentiation is shown with an explanation of the implication and physical significance of the method through the example. Being the first course in the sequence, the concept of the degree-long project, overview of the FSAE competition and the overall UC-ME curriculum are explained as a part of the assignment. This assignment is being implemented through Introduction to Mechanical Engineering II, the second of the three quarter courses sequence designed to engage ME freshmen with the department and department faculty.

Calculus III: (Planned to be implemented during spring quarter 2010 through Introduction to ME III)

Line and area integrals: Definition and the method to execute a line integral are taught using estimation of the length of a race track of the FSAE competition and the time required to drive along the path as example problems. The area integration is explained by taking examples of calculating the area of a structural part of the FSAE car, the first and second area moment of inertias. Because students have not learned the concept of the area moment of inertia yet, physical significance and definition of the area moment of inertia are explained in an intuitive way using graphical illustrations. Use of the change of variables in integration, and the methods to implement line and double integrations are discussed. The specific assignment is to evaluate various line and area integrations related to the design of FSAE cars.

Lagrange multiplier method: Design of the fuel tank to have the minimum weight for the given volume is the assignment in this project. Related mathematical concepts such as partial differentiation, gradient and tangential vectors, contour lines are explained in relation to the assignment. Ability to apply the method to solve a constrained minimization problem is what is expected from the students.

Physics II (Planned to be implemented during spring quarter 2010 through Introduction to ME III)

Application of the Newton's law to analyze motion and response of the FSAE car: The concept behind the Newton's second law students learned in Physics II is refreshed before the problem is assigned. Practices and techniques of using the free-body diagram are emphasized by taking examples from the motion analysis of the race car turning a corner. The method to describe velocity and accelerations using circular and curvilinear coordinates are also explained.

Second Year Courses

Mechanics of Solids (Planned to be implemented during spring quarter 2010):

Strength design of the suspension linkage: FSAE cars adopt double wishbone suspensions that can be viewed as a truss structure. Required analysis includes estimation of the maximum load applied to the linkage, force and stress analysis and buckling analysis of the truss element. Buckling phenomenon is explained as an elastic instability problem. Selection of the material and determination of the section size of suspension links are required based on the stress analysis results. A method to estimate proper safety factors is also learned. This project will be assigned as an individual project.

Kinematics of machines: (Implemented during summer quarter in 2009)

Design of FSAE car suspension: Kinematic design of the suspension system of FSAE car is conducted in this project. The double wishbone style suspension adopted in FSAE cars is viewed and modeled as a four-bar linkage. Vehicle dynamics concepts related to the suspension design such as the camber and the roll center are explained as a part of the assignment. The project task includes limiting the camber change within a permitted range by properly determining the geometry of links. Forces in the structural members are calculated by quasi-static analysis of the linkage. This project was assigned in Dynamics of Machine, a third year course, in summer quarter 2009. The scope of the project will be reduced and refined to be assigned as a kinematics project starting from fall quarter in 2010. Student survey was conducted to assess effectiveness of the project as a part of the degree-long project. The project was assigned as a team project of typical size of four students per team.

Third Year Courses:

Dynamics of Machine (to be implemented during summer quarter in 2010)

Motion of tire: Motion analysis of a tire in a rolling without slipping motion is conducted viewing the tire a rigid body moving in a two-dimensional space. Important concepts such as the instantaneous center, relative motion, rolling friction and sliding friction are to be taught through the assignment. The Coriolis acceleration and its effect are explained by viewing the tire as an elastic body having a rotational motion as well as a transverse motion. Estimation of the maximum acceleration from the torque data, relationships between power, torque and force of the engine are also required. The methods will be used again in the project to be conducted in ME422, a design course. This project is designed as an individual project.

Numerical Analysis (to be implemented during summer quarter in 2010):

<u>Motion analysis of the FSAE vehicle by numerical integration</u>: Formulation of the equation of motion of the FSAE vehicle is required. The traction force has to be derived from the engine performance data measured in the engine dynamometer as a function of the rpm. Numerical solution of the equation of motion is required, which includes the wind force given as a cubic function of the vehicle speed. Numerical integration of an initial value problem by the Runge-Kutta method using MATLAB® is conducted. This project is designed as an individual assignment.

<u>Fourth Year Courses</u>:

Design of Machine Components (implemented during summer quarter in 2009)

<u>Design of the driveline of FSAE car</u>: FSAE race cars use a purchased engine that comes with a built-in transmission. Therefore, the scope of the driveline that can be assigned is somewhat limited, which includes the chain-sprocket system, the rear axle, the floating shaft and the wheel bearings. The plots of the measured acceleration and engine power-torque measured from the engine dynamometer are given as the basic data for the students. The project is a prototypical open-ended project. Students have to estimate loading conditions from the acceleration data, load cycles of the car, and the weight data. The design requires structural life analysis based on the finite cycle fatigue failure theory. This project was assigned as a team project, each team typically composed of 4 members. Statistics based design was highly recommended, which was taken by about one third of team members. Student survey was conducted to assess the effectiveness of this project as a part of the degree-long project. Figure 1 shows a rendering of the design taken from one of the student reports submitted in 2009.

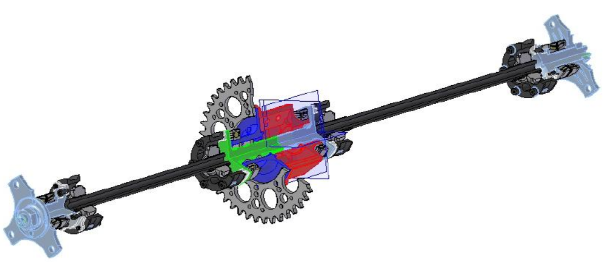

Fig.1 - Schematic that shows the plan for the rear axle and sprocket system. From left, knuckle, wheel bearing assembly, left-side floating shaft, differential gear assembly, rear sprocket, right-side floating shaft, wheel bearing and knuckle are shown.

Mechanical Vibrations I (implemented during fall quarter in 2009)

<u>Analysis of vibration response of FSAE vehicle using a two-degree of freedom quarter section car-body model and a four-degree-of-freedom half section car body model</u>: This assignment was designed to help students solidify their understanding of basic concepts taught in vibrations such as natural frequencies, natural modes, resonance and frequency response function. As an application example, students are asked to find the condition of the wheel hop. They learn to use a simplified model of the vehicle system according to the particular needs. The project also intends to train students for the ability to effectively utilize computer programming to solve engineering problems. Free and forced vibration problems are solved by using MATLAB® as the programming language. Eigenvalue analysis is conducted to obtain natural frequencies and modes. Frequency domain analysis is conducted to obtain and plot the frequency response functions (FRF) of the system. Students learn to relate the eigenvalue problem to the system natural frequencies, resonances and critical speeds. Finally, students are asked to perform time-domain integration to solve a transient vibration problem, response of the vehicle running over a bumper. Figure 2 shows one of the models, the 2-DOF model, assigned in the project.

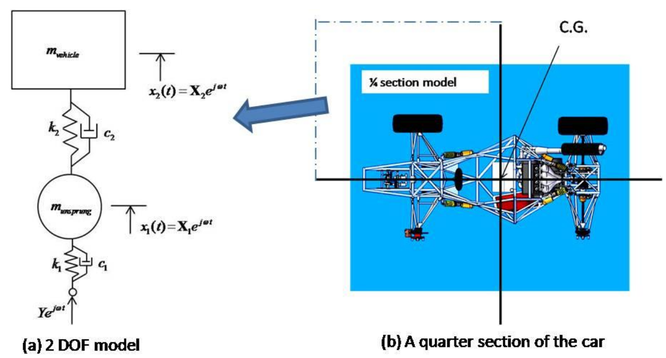

Fig. 2 - A quarter section FSAE car body modeled as a two-degree-of-freedom system with a road input defined as the displacement input.

<u>Fifth Year Courses</u>:

Automotive Engineering Design I, II and III (currently being implemented, in winter quarter 2010)

These automotive design courses are a three quarter, one year long sequence developed as a capstone design course at UC-ME. Students may elect this course in lieu of Design Clinic, the long-standing capstone design course sequence. First two quarters are spent to design, analyze and develop the race car for the year's competition. The efforts include design, economic analysis, fabrication and test of the race car and its parts. The last quarter is spent to summarize the effort and identify necessary improvement learned from the experience of competition. This sequence of the courses, which has been conducted for the last three years, will be revised to be more tightly integrated with the overall degree-long project from this spring quarter.

Outreach Programs for Area K-12 Students

During summers of 2008 and 2009, half-day workshops were offered showcasing the FSAE project degree-long project to area high school students and accompanying teachers to motivate their interests in design. In 2008, there were three workshops for a group of 33 students and 7 teachers who attended Men in Engineering week, a group of 25 students and 6 teachers who attended Women in Engineering week, and a group of 16 minority students and 4 teachers who attended E^3 (Emerging Ethnic Engineers) week at UC. In each of these workshops, the concept of the degree-long project paradigm was used to explain the relationship between fundamental math and science with engineering education. A hands-on experiment was conducted as a demonstration that shows how measurement and analysis are used in everyday engineering. Students participated in a group design completion that made a shock absorbing pad. Best designs were selected based on drop tests. In 2009, the workshops were given to two groups of students, for Men in Engineering participants, 32 students and 6 teachers, and Women in Engineering, 26 students and 4 teachers.

Fig. 3 - Summer workshop held in 2008 summer for Men in Engineering, area high school students aspiring to be engineers

ANALYSIS OF ASSESSMENT DATA

Student surveys were conducted during three courses in that degree-long project assignments were implemented, which were Kinematics of Machines (ME 320, suspension linkage analysis and design), Design of ME components (ME 422, driveline design), and Vibration (ME 480, analysis of vibration response of FSAE vehicle). 18 out of 47 students in ME 320, 21 of 45 students in ME 422 and 41 of 53 students in ME480 responded the survey questions. The survey asked 8 questions to be answered in the scale of 1 to 5 (with 5 being the strongest agreement), two questions to answer in yes/no and solicited written comments. Questions to be answered in 1-5 scales were:

1) Do you think the new approach enhanced your interest in the course?
2) Did the approach help you to understand how the course material is used for practical engineering problems?
3) Did the project experience improve your problem solving skill?
4) Did the project improve your communication skill?
5) Did the project help you to learn the course materials?
6) Was the project helpful in relating the course material and real-world problems?
7) Did the approach improve your interest in fundamental science and math courses?
8) Were the course and project well organized in a relevant manner?

Two questions, if they want to take another course project designed as a part of the degree-long project, and if they will recommend other to participate, were asked for a yes/no response. Fig. 4 shows the chart that summarizes the student responses to the 8 questions asked in 1-5 scales. It is seen that responses to question 4 were poorest for all three courses, which was because communication skills were not formally emphasized in any of the course assignments. ME 480, Mechanical Vibrations I shows significantly more positive responses in all questions. It is interesting because the course project was an “analysis” type while the projects in the other two were “design” type project. The result may reflect that non-design courses can be more significantly benefitted by adding a project with implications of practical engineering. Improved maturity and attitude of students may have been another factor because ME480 is a course taken in the 4^{th} year of the program while others were the third year courses.

In response to the two yes/no questions, 67% of the students responded in ME 320 said they would take another degree-long project and 78% said they would recommend others to participate in the approach. The percentages were 90.5% and 76.2% in ME 422, and 90.2% and 90.2% in ME480. Although three courses do not form sufficient basis, these questions showed that the project in ME 480 was received better by the students. Additional surveys to come in course over the full 5 years range will provide more clear indications.

About 30% of students who participated in surveys offered written comments. In all the courses, comments were generally positive except one or two negative comments. All positive comments mentioned the benefit of the approach for exposing them with realistic problems. Most common suggestions were having some components of hands-on experience in the assignment.

A different set of surveys were conducted for the outreach programs. The questions were to gauge the response of students if the workshop improved their interests in engineering education and enhanced recognition of need of STEM education. All participants, students as well as teachers, returned very positive responses, resulting in average score of 4.5 in the same 1-5 scales for the questions.

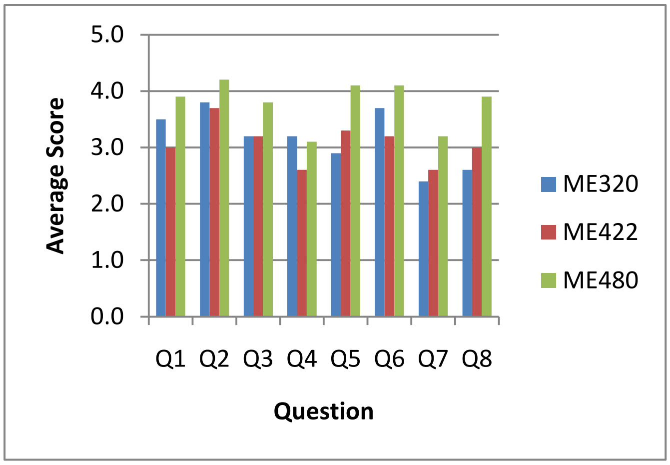

Fig.4 - Summary of student survey responses taken in the three courses where an assignment was implemented as a part of the degree-long project.

DISCUSSIONS AND CONCLUSIONS

Possibly the biggest advantage of the proposed approach, engineering education through degree-long project experience, is that it helps students to see individual courses from the perspective of the overall curriculum. Explanation of the overall concept of the degree-long project gives students a sense of purpose of learning and how the course is related to the other courses. This is especially beneficial in fundamental courses taught in early years. However, developing good problems was much more difficult than expected especially in early year courses. Ideally the problem has to be highly relevant to the main content of the course as well as the theme of the project. Obviously the task becomes more difficult in first year courses where very fundamental and simple concepts are taught.

Deriving course assignments from the degree-long project generally helped, as the project provides natural example problems. However, strictly limiting the scope of the problem only within the scope of the degree-long project worked against in some courses. For example, the engine with a built-in transmission and the differential gear are purchased to build FSAE cars; therefore design of the transmission is not the scope. Design of a gear train will make a very good problem for ME 422, a course that teaches gears, shaft and bearing designs; however was not chosen for this reason. A possible option may be letting students to design the transmission and compare the size and specification of their design with that of the purchased unit.

Our initial plan was developing multiple degree-long projects that students can choose. However, it was very difficult to identify a practical industry project whose scope is comprehensive enough to be integrated with courses across the entire ME curriculum. It is believed to be better to identify a few projects of smaller scope to complement the current degree-long project. For example, problems derived from multiple engineering applications may be used in addition to the FSAE themed problems in early year courses.

The followings are near-term future plans to complete the first phase of the proposed paradigm.

(1) Workshop with major stakeholders (planned in May 2010): Advisors from industry and area universities, faculty members and students of UC-ME and faculty members of math and physics at UC will be invited. The concept and achievement of the degree-long project will be presented to the participants. Open discussion and a panel discussion will follow that will encourage them to participate in the follow-on action plan.

(2) Development of a system to further and improve the degree-long project paradigm: A membership system will be initiated using a supporting web site developed using the Blackboard® that will provide all necessary functions including discussion board and group functions. The details of the system will be decided reflecting the discussions and outcomes to be made in the workshop. It is the current plan to develop a project/problem bank system. Participants will be able to become members in various ways, for example by contributing ideas and topics of engineering problems, providing design of problems, suggestions or critiques to improve the approach or existing problems. Problems and projects developed will be posted in the web site, which will be constantly updated by reflecting inputs from the participants.

(3) Assessment functions will be developed as a part of the Blackboard based web site so that members can use. Providing such benefits is expected to entice more users to enlarge the user basis. The system will also be used to incorporate a team to implement the proposed paradigm and develop future education projects.

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REFERENCES

1. Dym, C.L., "Design Systems and Engineering Education", *Int. J. of Engineering Education.* 20(3), 2004, pp 305-312.

2. Dally, J.W. and Zhang, G.M., "A Freshman Engineering Design Course," *J. of Engineering Education,* 83(2), 1994, pp. 83-91.

3. Quinn, R.G., "Drexel's E^4 Program: A Different Professional Experience for Engineering Students and Faculty," *J. of Engineering Education*, **82**(4), 1993, 196-202.

4. Ulrich, K.T. and Eppinger, S.D., *Product Design and Development*, 3rd ed., New York., N.Y.: McGraw-Hill, 2003.

5. McMaster, J.H., "Influencing Engineering Education: One (Aerospace) Industry Perspective," *International J. of Engineering Education*, 20(3), 2004, pp. 353-371.

6. Fielder, R.M. and Brent, R. "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *J. of Engineering Education*, 92(1), 2003, pp. 7-21.

7. Duston, A. J., Todd, R.H., Magleby, S.P., and Sorenson, C.D., "A Review of Literature on Teaching Design through Project-Oriented Capstone Courses", J. of Engineering Education, 76(1), 1997, pp. 17-28.

8. Pimmel, R., Todd, R.H. "Cooperative Learning Instructional Activities in a Capstone Design Course," *J. of Engineering Education*, 90(3), 2001, pp. 413-421.

9. Lewis, W. P. and Bonnolo, E., "An Analysis of Professional Skills in Design: Implication for Education and Research," *Design Studies*, 23(4), 385-406, 2002.

10. Seidman, G.E., and Brown, D.L., "Engineering Design Clinic Internship Program," Compendium to the *ASME Design Education Conference*, pp 15-17, 1993.

11. Froyd, J.E. and Okland M.W. "Integrated Engineering Curricula," *J. of Engineering Education*, 94(1), 2005, pp. 147-164.

12. Agognio, A.M., Sheppard, S.D., and Oladipupo, A., "Making Connections to Engineering during the First Two Years," Proc., 1992 *Frontiers in Education Conference*, IEEE.

13. Anderson, H, "Experiences from a Pedagogical Shift in Engineering Education," *Global J. of Engineering Education*, **6**(2), pp. 139-144, 2002.

14. Dym, C.L. and Little, L., *Engineering Design: A Project Based Introduction*, 2nd ed., New York, N.Y.: John Wiley, 2003.

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