# 2006-2292: A MODULAR APPROACH TO COMBINING FIRST-YEAR DESIGN EXPERIENCES ACROSS ENGINEERING DISCIPLINES

**Marc Christensen, Southern Methodist University**

Marc P. Christensen received the B.S. degree in engineering physics from Cornell University, Ithaca, NY, in 1993 and the M.S. and Ph.D. degrees in electrical engineering from George Mason University, Fairfax, VA, in 1998 and 2001 respectively. From 1991-1998, he was a Staff Member and Technical Leader in the Sensors and Photonics Group, BDM International, Inc., where his work ranged from developing optical processing and interconnection architectures, to infrared sensor modeling and analysis. In 1997, he cofounded Applied Photonics, where he was responsible for several prototype developments that incorporated precision optics and microoptoelectronic arrays into system level demonstrations. In 2002 he joined Southern Methodist University, Dallas, TX, where he is currently an Assistant Professor of electrical engineering. He has coauthored 12 journal papers and holds two patents in the field of free-space optical interconnections. Prof. Christensen was the Workshop Chair for the IEEE Communications Society Workshop on High-Speed Interconnections within Digital Systems in 2002. He is a member of the Optical Society of America and the IEEE Communications and Lasers and Electrooptics Societies.

**David Willis, Southern Methodist University**

David A. Willis is an Assistant Professor in the Department of Mechanical Engineering at Southern Methodist University. He received the B.S. degree in Mechanical Engineering from North Carolina State University (1995) and M.S. (1997) and Ph.D. (2001) degrees in Mechanical Engineering from Purdue University.

Dr. Willis actively performs research in laser processing and thermal sciences. He developed the Laser Micromachining Laboratory at SMU, where he and his research team study thermal transport during laser-material interactions and laser micro-processing. His recent works have been published in the highly visible journals Physics of Fluids, the International Journal of Heat and Mass Transfer, and the Journal of Heat Transfer. He is a member of the American Society of Mechanical Engineers, SPIE-The International Society for Optical Engineering, and the Laser Institute of America. He is actively involved in laser processing conferences through these societies, both as a participant and as a topic organizer.

In addition to his research program, Dr. Willis is active in education and outreach programs. He serves on the School of Science and Engineering Advisory Board at Newman-Smith High School (Carrollton, TX) and is the faculty co-advisor for the student chapter of the American Society of Mechanical Engineers at SMU. For the past two years Dr. Willis has collaborated with Dr. Marc Christensen (Electrical Engineering) to develop an interdepartmental freshman design program in which electrical and mechanical engineering students design and building working prototypes.

Dr. Willis received the Golden Mustang Outstanding Faculty Award at SMU (2005), the Outstanding Graduate Faculty Award from the SMU Department of Mechanical Engineering (2003) and the Magoon Award at Purdue University (2000).

**Scott Douglas, Southern Methodist University**

Scott C. Douglas is an associate professor in the Department of Electrical Engineering at Southern Methodist University, Dallas, Texas and the Associate Director for the Institute for Engineering Education at SMU. He received his B.S., M.S., and Ph.D. degrees from Stanford University. Dr. Douglas' is a recognized expert in the fields of adaptive filters, blind source separation, and active noise control, having authored or co-authored two books, six book chapters and over 150 journal and conference papers in these fields. He was the recipient of an NSF CAREER (Young Investigator) Award in 1995 and has received significant research funding from the U.S. Army, other U.S. governmental organizations, the State of Texas, and Raytheon

E-Systems Company. He is highly active in professional societies. He has been an Associate Editor of both the IEEE Transactions on Signal Processing and the IEEE Signal Processing Letters and is past Chair of the Neural Networks for Signal Processing Technical Committee and Secretary of the Signal Processing Education Technical Committee of the IEEE Signal Processing Society. He is regularly involved in organizing professional meetings, most notably as the Proceedings Editor of the 1999 International Symposium on Active Control of Sound and Vibration and the Proceedings Co-Editor of the IEEE Workshops on Neural Networks for Signal Processing and Machine Learning for Signal Processing since 1999. He has given a number of keynote and invited lectures as well as short courses on topics ranging from adaptive signal processing and control to innovative engineering education methods. Most recently, he has co-authored a textbook, Engineering Our Digital Future (Prentice Hall, 2004), that is a key component of The Infinity Project, a multi-faceted effort to establish a nationwide engineering curriculum at the high school level. Dr. Douglas is a frequent consultant to industry, a senior member of the IEEE, and a member of both Phi Beta Kappa and Tau Beta Pi.

# A Modular Approach for Combining First-Year Design Experiences Across Engineering Disciplines

Abstract: We describe a joint effort to integrate engineering design in the first-year courses across the curricula of multiple departments at the host institution. A modular design approach allows for student interaction and teaming across two different design exercises, and early exposure of students from each engineering discipline is emphasized. Survey results indicate that the intervention is helpful in promoting engineering design and inter-discipline awareness for the students.

## 1. Introduction

Recent data collected from U.S. colleges and universities indicate that fewer and fewer students are electing to study engineering. The number of students who study in all undergraduate engineering fields dropped from nearly 450,000 in 1983 to approximately 360,000 in 2000[1]. As of 2003, about 2% of all U.S. high school graduates attain a degree in an engineering field[2], with low representation from underrepresented groups[3]. About one out of every 100 female high school graduates attains a bachelor of science degree in an engineering field, and only one out of every 125 minority high school graduates achieves such a degree[2]. Given the corresponding increase in the advancement of technology over the past decade—exemplified by the rise of the Internet, the implementation of cellular and broadband wireless infrastructure, and the digitization of popular audio and visual media—such a decline is both surprising and detrimental to the long-term sustenance of our modern technology-driven society.

Addressing this decline in engineering enrollments is likely to require a multi-faceted approach to recruitment, retention, and graduation of engineering students. Recruiting strategies in the precollege arena include 1) robotics competitions such as FIRST and BEST, and 2) educational programs such as Project Lead-the-Way, The Infinity Project, and Cisco Academies, which introduce and bring awareness of engineering principles and opportunities to young people in the classroom. These efforts set the stage for curricular changes at the college level, as students who are intrigued by engineering through a pre-college experience are likely to expect a four-year engineering education that is exciting, creative, and engaging from the moment they start their college careers. Many engineering schools are responding to the needs of such students by either offering new or re-tooling their existing introductory engineering curricula and experiences. Examples include the Engage Engineering Fundamentals Program at the University of Tennessee, the General Engineering Program at Clemson University, and the Texas Engineering Education Pipeline, a consortium of fourteen Texas universities funded through the joint governmental-industrial Texas Engineering and Technical Consortium (TETC).

The implementation of introductory engineering curricula depends strongly on the structure of the particular college or university's curriculum. Many college engineering retention studies agree that the first year of study is extremely important in determining if a student will persist and graduate with an engineering degree[4]. In institutions that have a common first-year engineering curriculum, it is possible to completely change the first-year experiences of all engineering students through the retooling of the common courses. At other institutions where individual departments offer first-year introductory courses, curriculum changes must involve activities in multiple departments to be successful across the engineering college or school.

In this paper, we consider a retention strategy based on students' exposure early on to the excitement of collaboration and design across engineering disciplines. The strategy employs significant cross-disciplinary engineering design experiences for first-year students, in which students with different technical backgrounds work together on hands-on design problems. The proposed curricular enhancement employs a modular approach that allows students to practice the important activity of working in teams in multiple contexts and reinforces the practical aspects of engineering design that the students will experience later in their careers.

Our approach has a number of unique features:

- It can be implemented in universities where course content and requirements are unique for each specific major.
- It does not impose a common interdisciplinary "introduction to engineering" course, in which all students participate in the same lectures and laboratories[5-8], thus maintaining the diversity of each department's teaching and scheduling resources.
- It involves course content change only; thus, there is no impediment to implementation caused by administrative changes to degree plans, graduation requirements, and the like.
- It provides a balance between the conflicting needs of (a) offering enough technical content to allow a student to evaluate her or his choice of major and (b) showing the student what the content and methods used in another related major are like.
- It can be taught by discipline-specific faculty who normally teach such courses -- "super-faculty" that have deep knowledge of multiple engineering fields are not required.
- It shows students what "real engineering life" is like, where the likelihood of engineers with diverse engineering backgrounds working together is high.

The efficacy of our approach has been demonstrated through three semesters of survey data at the host institution, in which students point to the multi-disciplinary engineering design experience as a desirable component for all of their future engineering courses.

## 2. Curriculum Description

The proposed cross-disciplinary design experiences have been implemented with slight variations in the Spring 2004, Fall 2004, Spring 2005, and Fall 2005 courses within the Departments of Electrical Engineering and Mechanical Engineering at the host institution. Our strategy for introducing engineering design in first- and second-year courses begins with determining two design projects to be attempted in each semester of a set of courses across two or more departments. The mark of an appropriate design project is that it requires skills that cannot all be acquired in a single discipline or class but rather are the union of skills acquired from multiple disciplines and classes. Thus, no one student will possess all the knowledge to complete the design project, and groups of students must learn to work together in a creative and dynamic problem solving team. The size of each team depends somewhat on the number of students enrolled in each course in each semester but typically has numbered between five and eight students. The reasoning behind the use of two distinct design projects is that the first, less-demanding design project serves as a "dry run" of the longer end-of-semester design project. During the first design project, each group learns how to function efficiently, and each individual learns how other members of the team can be a valuable resource in the design effort—important lessons for the budding engineer. The second design project allows the same team to revisit these issues in a more-challenging task to figure out what strategies do and do not work. We believe that this team interaction is one of the most important and rewarding aspects of engineering, and students should be exposed to this interaction as early as possible in their careers.

The first design project is assigned after basic engineering design concepts have been introduced in both course lectures. The task is to build a working loudspeaker from ordinary household items. Since the students generally have not received much training in mechanical or electrical engineering, this initial project focuses on learning the design process, techniques of communication, and teamwork. Students are given only two constraints in the forms of a standardized piece of wire and a magnet that has to be used in their speaker construction. Students are divided evenly into teams, in which the number of mechanical engineering and electrical engineering students on each team is approximately the same. The students then build two sets of designs—one of their own personal construction, and one which fuses the best parts of each person's design within the group. This joint loudspeaker design is then evaluated against the designs conceived by the other teams in the class according to its physical attributes—efficiency, frequency response, and "musicality." The grade for each student is based on a group report on the final loudspeaker design of each group. This initial project focuses on learning the design process, techniques of communication, and teamwork.

The second joint design task is a five-week activity to construct a robot capable of playing "putt-putt" golf. The design project has two subtasks: 1) the design of an overhead vision system to determine the distance from the golf ball to the hole, and 2) the design of a hitting mechanism to "take the shot". Depending on the semester, certain constraints have been removed from the game of golf. For example, in Spring 2004, students were allowed to load the ball by hand into their robot after each shot if their robot design required such loading. In all later design projects, students had to construct systems to orient the robot and/or load the ball without a human hand if their design required such loading. Each team is provided DSP hardware and software, a web camera, three motors, and batteries. All other materials and aspects of the design are left up to the students. Additional software and hardware components from the Infinity Project engineering curriculum are employed to assist in hardware implementation and software programming[9-10]. Each student is graded on her or his performance in the design project through (i) a group report and (ii) individual presentations that are evaluated by outside faculty.

The vision systems constructed by the student teams in each semester for judging ball-to-hole distance have been similar, being based on graphical software modules that are in use in the course laboratory for the Electrical Engineering course. The students rely on their understanding of simple image processing concepts as taught in the course to develop a logical strategy for taking an overhead web camera image of the golf course, determining the ball and hole positions within this image, and calculating distance from the identified locations. Issues of calibration, geometry, and reliability play an important role in these students' designs. During the testing phase, the information collected is passed to the team members who are responsible for initiating the golf play of each team's robot.

One such design is depicted in Figure 1. A web camera captures an overhead image that is read into the Infinity Project VAB software environment with a Bitmap Read block. At this point the block diagram worksheet follows two parallel paths. One path finds the location of the golf ball (in pixels), and the other finds the location of the hole. Color distinction is used to locate the golf ball or hole. A mask is created which contains all pixels that match the object of interest (golf ball or hole). This mask is then fed to an object tracking routing block that identifies the co-ordinates of each group of pixels of the appropriate size in the mask. The specific object to be tracked can be selected with an ordinal parameter. At this point, enough information is available within the worksheet for the student to calculate the position (in terms of pixel rows and columns) of the golf ball and hole in the image. The final distance is calculated using a distance formula that incorporates separate calibration settings for the pixels/meter in the horizontal and vertical directions. In this way, an overhead view of the golf course can be used to determine a between an arbitrarily placed golf ball and hole in the view of the camera. This distance was then communicated down to the crew operating the putting robot on the playing field during the end-of-semester putt-put golf competition.

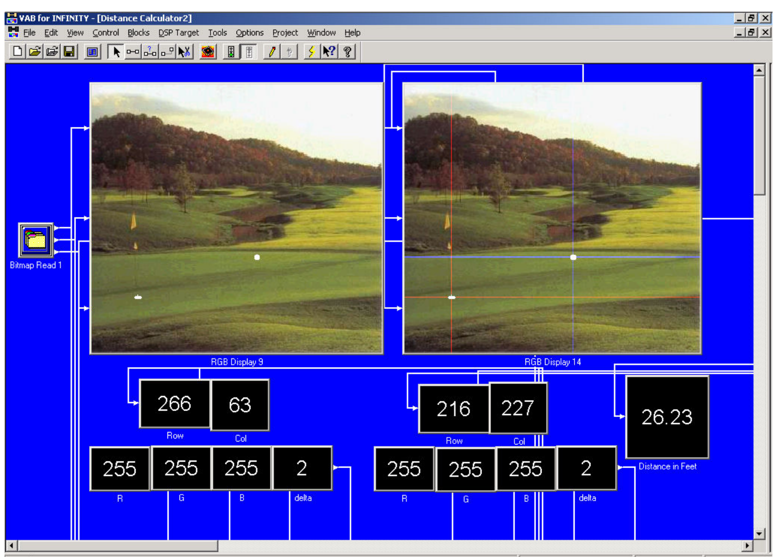


Figure 1. VAB worksheet for an putt-putt vision system using an image captured by a web camera. This golf image is a simulated bitmap input as

opposed to the overhead web camera data employed
in the actual competition.

The physical designs of the golf-playing robots have been varied and have involved pendulums, plungers, ramps with motorized ball lifters, and wheel-based systems. Methods for controlling shot distance have varied and have included position and height variations of ramps or clubs. Moreover, while all robots had to be controlled using digital hardware from the Infinity Project and programmed using the same graphical software as was used to create the overhead vision system, students have developed different strategies for this control that generally use a combination of timing and position information to set up "the shot." Two example robots are shown in Figure 2.

Figure 2. A ramp and a putter style golf robot using DSP control for height and backswing timing, respectively.

Figure 3 outlines the above two design projects in their relation to important concepts taught within each introductory course within the associated departments. The main requirements for these projects are: (a) they must teach a set of important principles specific to each course discipline at the time of their completion, and (b) they require different concepts from each discipline in order to complete the design process.

| | Skill Acquired in ME class | Skill Acquired in EE class |
|---|---|---|
| **Skills required for Design Project #1: Loudspeaker Construction** | | |
| Engineering Design Process | ❍ | ❍ |
| Written Communication Skills | ❍ | ❍ |
| Sketching | ❍ | |
| Audio Signal Processing | | ❍ |
| **Skills required for Design Project #2: Putt-putt playing Robots with Vision System** | | |
| Engineering Design Process | ❍ | ❍ |
| Written Technical Communication Skills | ❍ | ❍ |
| Basic Mechanics | ❍ | |
| Conservation Laws | ❍ | |
| Manufacturability and Machine Shop Skills | ❍ | |
| Video Signal Processing | | ❍ |
| Block Diagrams | | ❍ |
| Control Systems Approach | | ❍ |

Figure 3. Typical breakdown of skills necessary for successful design projects showing that only through the combination of skills acquired by ME and EE students can the design goals be successfully achieved.

3. Curriculum Assessment

For the assessment of this activity, a short survey has been administered to the students to query their interest on a number of attributes of the class since the Fall 2004 semester. Both means and standard deviations (in parentheses) are listed for both semesters in the table below. Participation in this survey and the competition was voluntary; grading of each team's design was based on oral presentations and written reports.

| QUESTION | FALL 2004 (Ntotal = 80, Nsurvey=30) | SPRING 2005 (Ntotal=22, Nsurvey=10) | FALL 2005 (Ntotal = 96, Nsurvey=21) |
|---|---|---|---|
| 1. How would you rate the Design Experience? (1=poor, 5=excellent) | 4.10 (0.80) | 3.90 (0.32) | 3.81 (0.75) |
| 2. How interested would you be in having design experiences in future engineering classes? (1=not at all, 5=very interested) | 4.57 (0.82) | 3.60 (1.35) | 4.29 (0.85) |
| 3. The combination of students from multiple departments enhanced the design experience. (1=completely disagree, 5=completely agree) | 3.69 (1.14) | 4.00 (0.87) | 3.86 (1.31) |
| 4. This design experience made me more or | 3.93 (1.00) | 4.00 (0.81) | 4.14 (0.79) |

| | | | |
|---|---|---|---|
| less likely to pursue an engineering degree: (1=very unlikely, 5=very likely) | | | |
| 5. How much "engineering" did you learn from this design experience? (1=absolutely nothing, 5=a lot) | 3.53 (0.86) | 3.75 (0.98) | 3.76 (0.77) |
| 6. How much "team / project management" did you learn from this design experience? (1=absolutely nothing, 5=a lot) | 3.90 (0.99) | 4.20 (0.79) | 3.81 (1.08) |
| 7. If the same class was offered with and without a design experience how likely would you be to choose the class offering with a design experience? (1=very unlikely, 5=very likely) | 3.73 (1.39) | 3.30 (1.16) | 3.76 (1.37) |

Question 2 received the most one-sided responses in the large-enrollment Fall semesters. Incoming students clearly want more design experiences as part of their courses. In Spring Semester 2005, students responded strongest to the team/project management component of the design experience. All of the responses are generally positive as well. In all three semesters, students appreciated the design experience. Moreover, they were self-motivated to achieve substantial outcomes *as first-year students* with these activities in place.

## 4. Recommendations for Adopters and Future Work

Administering a cross-disciplinary design experience between first-year courses from multiple engineering disciplines requires coordination between the faculty and teaching assistants of both courses. Scheduling of common laboratory times is the most important logistical issue to allow easy collaboration across disciplines. As the intervention utilized existing hardware and software capabilities, the cost of materials was not prohibitive. Additional support time is required to administer the design experiences, particularly in terms of support staff (to help them fabricate parts for their robots in the ME shop, for example). The design challenges fit both courses, and both faculty instructors indicate that they had ample time to teach their discipline-specific concepts.

Assessment of each student's performance is based on an individual oral presentation and a written description of their robot design as submitted by the entire group. Students are also given the opportunity to self-assess their group's performance to identify specific individual contributions made by each team member using a survey instrument. In most cases, these students identify the contributions made by others as opposed to touting just their own work.

Future work shall focus on the development and exploration of possible design projects that both serve the content needs of the courses in which they are embedded and provide opportunities for cross-disciplinary student interaction. Table 2 lists example candidate design projects for both the initial three-week design experience as well as the five-week end-of-semester design experience, along with the engineering disciplines involved for each. This list is not meant to be exhaustive; rather, it is to show how engineering disciplines can be grouped according to specific cross-disciplinary design activities.

Table 2: Example Candidate Design Projects

| 3-Week Mid-Semester Design | 5-Week End-of-Semester Design | Possible Engineering Disciplines Involved |
|---|---|---|
| Design of a Safe with an Electronic Key | Design and Build a Wastepaper Basketball Shooting Robot | Electrical Engineering, Mechanical Engineering |
| Design of an Campus Automobile Traffic Management System | Design/Layout of Campus Parking Structures | Computer Science, Engineering Management, Environmental/Civil Engineering |
| Design of a Campus Interoffice Mail Delivery System | Develop a Class Scheduling Program | Computer Science, Engineering Management |
| Assess Air and Noise Pollution on Campus | Mock-up Design of a Deep-Space Planet Rover | (multiple engineering fields) |

## 5. Conclusions

In this paper, we have presented modular curricular enhancements whereby first-year students enrolled in discipline specific engineering courses work in inter-disciplinary design teams across multiple engineering fields to solve a relevant engineering problem. The methods have been implemented over several semesters at the host institution, and survey data indicate that students find these design experiences to be a desirable component to these courses. Additional modules that offer cross-disciplinary design experiences are indicated and are currently being pursued, along with a longitudinal study of students who have participated in the design experiences at the host institution.

## References

[1]National Science Board, 2002, "Science and Engineering Indicators," National Science Foundation, Arlington, VA.

[2]U.S. Dept. of Education, 2003, U.S. high school graduate information collected from the U.S. Department of Education web site (www.ed.gov) in conjunction with college engineering graduate information from the National Science Foundation.

[3]R.J. Noeth, T. Cruce, and M.T. Harmston, 2003, "Maintaining a strong engineering workforce," ACT Policy Report, Iowa City, IA.

[4]C. Moller-Wong and A. Eide, 1997, "An engineering student retention study," *Engineering Education*, Vol. 86(1), pp. 7-15.

[5]J.D. Bronzino, D.J. Ahlgren, C.-L. Chung, J.D. Mertens, and J.L. Palladino, 1994, "Design and teamwork: A must for freshman," *IEEE Transactions on Education*, Vol. 37(2), pp. 184-188.

[6]J. Richardson, C. Corleto, J. Froyd, P.K. Imbrie, J. Parker, and R. Roedel, 1998, "Freshman Design Projects in the Foundation Coalition," *Proceedings of the Frontiers in Education Conference*, Vol. 1, pp. 50-59

[7]M.A. Angelov, M.B. Friedman, A.A. Renshaw, 1999, "Introducing engineering design into the first year curriculum," *Proceedings of the Frontiers in Education Conference*, pp. 12a6-7-12a6-12.

[8]J. Richardson and J. Dantzler, 2002, "Effect of a freshman engineering program on retention and academic performance," *Proceedings of the 32nd Frontiers in Education Conference*, pp. S2C-16 – S2C-22.

[9]G.C. Orsak, S.L.Wood, S.C. Douglas, D.C. Munson Jr., J.R. Treichler, R. Athale, and M.A. Yoder, 2004, *Engineering Our Digital Future,* Pearson Prentice Hall, Upper Saddle River, NJ..

[10]M.P. Christensen, S.C. Douglas, S.L. Wood, C. Kitts, and T. Mahler, 2004, "The Infinity Project brings DSP brains to robots in the classroom," *Proc. 11th Digital Signal Processing and 3rd Signal Processing Education Workshops*, Taos, NM, August 2004.