An Interdisciplinary Practice-Based Design Course for First-Semester Juniors

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I. Introduction

Baylor University undergraduate engineering students are introduced to engineering design in a required first-semester course (EGR 1301 – Introduction to Engineering) and conclude with a required final-semester senior course (EGR 4390 – Engineering Design II). Additional exposures to design, of various types and amounts, occur throughout the curriculum in required and elective courses involving specific technical areas. In addition to these design experiences, which are similar in form to those in many engineering undergraduate programs, Baylor undergraduate engineering students take a required first-semester junior course in design, EGR 3380 – Engineering Design I, commonly known as Junior Design.

Our objectives in placing a comprehensive design course at the midpoint of the curriculum are: to provide students with a motivating and peer-bonding experience; to reinforce the importance and application of the fundamental concepts they have been, are currently, and will be learning; to develop and promote a professional attitude among students toward engineering; and, to develop students' teamwork, communication, project management, and ethical skills. We believe that the accomplishment of these objectives can contribute toward the larger goal of improving the level of student performance and success in the engineering upper division.

To provide an interdisciplinary experience, the freshman introductory course, the junior design course, and the senior design course are taken in common by all engineering students. These include students majoring in mechanical engineering, electrical and computer engineering, and engineering. In addition, a few non-engineering majors pursuing engineering minors take the freshman and junior courses.

The 2001-02 Baylor University Catalog description of this course reads: EGR 3380 Engineering Design I (prerequisite: upper division admission). Introduction to the engineering design process via team-based projects encompassing the design, construction and testing of an engineering device or system. Projects will emphasize oral, written and graphical engineering communication skills and topics related to engineering professionalism.

This junior design course was introduced at Baylor in 1992. Although the content has evolved over the years, it has always been required of all engineering students. In teams of three to five students (depending on the specific semester), students proceed through the major design stages from problem specification to final prototype compliance test, with a different project each semester.

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Admittedly, as first-semester juniors the students do not have a strong technical base for engineering analysis and design. Indeed, they begin the semester having completed only Statics and Circuits (and, for the ME's, Dynamics; and for EGR's, Thermodynamics). However, the emphasis in junior design is on the design process: RFP, brainstorming, conceptual design, conceptual plans and specifications, subsystem design and test, engineering drawings, integration tests, design iteration, final design plans and specifications, prototype construction, compliance test, and final report. A major goal is to prepare students to enter the senior design course with experience in design and project management, allowing them to function more smoothly in the senior design course while concentrating on the more rigorous technical design and analysis that will be required in that course.

The following sections describe the course, including typical junior design projects, design process implementation and assessment tools, use of oral, written and graphical communication skills, professionalism topics and other features of the course, together with representative student course evaluations and faculty observations.

II. Context

The Department of Engineering at Baylor University currently offers a B.S.E. degree with majors in electrical and computer engineering (ECE), mechanical engineering (MEC), and engineering (EGR). (The engineering major allows students the flexibility to pursue a *concentration* that can be either of an interdisciplinary nature within engineering, or can be in a subject outside of engineering but which supports some well-defined career goal of the student.) The course is team taught by two, and sometimes three, engineering faculty members, with at least one faculty member from each of mechanical engineering and electrical and computer engineering. (This same staffing arrangement also applies to the senior engineering design course.) Enrollment is typically about 30 students in the fall semester and 15 students in the spring semester.

III. Design Projects

Because the beginning juniors do not yet have broad backgrounds in specific technical subject areas, projects which allow students to exercise their ingenuity and creativity without having to rely on extensive analysis are typically chosen. Each project requires that teams of students complete the entire cycle of the design process beginning with a statement of need and continuing on through the construction, testing and evaluation of a functional prototype. In a typical semester, each student must complete two design projects: a three-to-four week mini-project (Phase 1) at the beginning of the semester followed by a larger project (Phase 2) that consumes most of the remainder of the term. Depending on the semester, the Phase 1 project may or may not be related to, or be a sub-set of, the Phase 2 project.

The most significant difference between the two phases, besides the time allotted, is that the documentation and reporting requirements for the Phase 1 project are minor compared to those for the Phase 2 project. In Phase 1, teams are given a statement of need and are advised of a date three-to-four weeks in the future – compliance test day – on which they must demonstrate a working prototype to satisfy the statement of need. In the interval, each team is typically only

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required to have one formal meeting with the faculty, during which they submit and discuss conceptual plans and specifications for their design, and discuss plans for implementation. Class sessions during Phase 1 are divided between formalized discussions of concepts related to the design process and informal sessions during which teams can meet, discuss their plans, and seek help from the faculty.

The students perform the majority of the construction on their projects using tools available to them in the junior design laboratory. This laboratory is a combination of workshop and office, with an assortment of hand tools, power tools, and workbenches, as well as with space for teams to hold meetings, to study, and to store their materials. The junior design students also have access to the services of the department machinist and the department electronics technician. In most semesters, the students purchase the materials they need at their own expense. There is no textbook required for the course, so they operate under the guideline that each individual student may spend an amount on materials during the course not to exceed the cost of an average engineering textbook (approximately $100). However, a company specified and funded the project for the fall 2001 semester.

The majority of students enter the junior design course with little or no experience using tools, little knowledge of materials, limited construction and assembly skills, and limited intuition about what types of things tend to work or not work, or can or cannot be done, both mechanically and electrically. The Phase 1 project grew out of a desire to ramp-up their skills and knowledge in these areas rather quickly in preparation for the more involved Phase 2 project. With the *crash-course* experience they gain in Phase 1, they approach Phase 2 with more confidence in their own capabilities, and with an ability to include more realistic detail in their planning during the conceptual and preliminary design stages.

For semesters in which it is unrelated to the Phase 2 project, the Phase 1 project is typically devised to model some manufacturing or materials handling process, but usually in an informal way. For example, during the spring semester of 2000, the Phase 1 project specified the design and construction of a device which will, upon a start signal, remove a golf ball from a tee centered upon a table top, transport the ball off the table, underneath the table, and up the other side of the table, and deposit it in a cup sitting a distance of one foot from the location of the tee. In addition, the ball must be delivered to the cup at a time of 10 (± 1) seconds from when it begins its travel. In solving this problem, some teams employ strictly mechanical means of transporting the ball and achieving the specified time delay. Other teams achieve the proper timing by employing electronic timers to control actuators – typically dc motors and/or solenoids. Team size for this type of project is typically 3-4 people, with ECE, MEC, and EGR students mixed. A Phase 1 device from the fall semester of 1998 (the project was similar to the golf ball transportation described here for spring of 2000) is seen in Figure 1.

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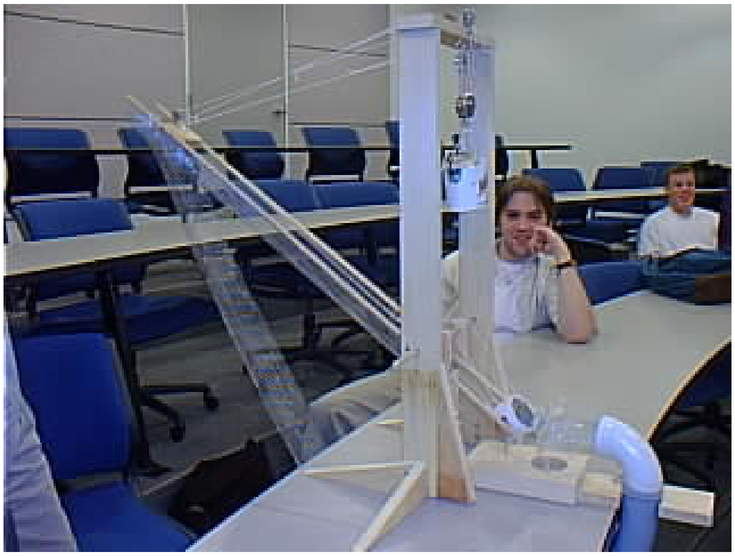

Figure 1. Phase 1 device from fall semester 1998

The duration of a Phase 2 project is typically 8-9 weeks. In addition to the design problem being of greater complexity, the documentation and reporting requirements are much more substantial than for Phase 1. On three occasions, the American Society of Mechanical Engineers (ASME) national student design competition was selected to be the fall semester Phase 2 junior design project. Student design teams have then been able to enter their devices in the regional competition in the spring. This was most recently the case in the fall semester of 1999. The ASME competition project for the 1999-2000 school year was to design a device which will transport, fill, and cap a 1 liter plastic bottle – a problem which is modeled after a soft drink bottling process. The fall 1999 semester was an example of the case for which the Phase 1 project was a subset of the Phase 2 project. In Phase 1, each design team was responsible for developing a device to perform only one of the major functions of the overall bottling device: transporting, filling, or capping the bottle.

In the spring semester of 2000, the Phase 1 project was loosely coupled with the Phase 2 project. In Phase 2, design teams were asked to design and construct a golf ball *quality control system*, which included designing an electronic scale with which to measure and digitally display the weight of a golf ball, as well as a system for transporting golf balls one at a time from an input bin to the scale and from the scale to an appropriate output bin, depending on the weight of the ball. The Phase 1 project of transporting golf balls (described above) was designed to facilitate students' understanding of the issues related to handling the golf balls. Class sessions during Phase 2 are utilized either informally for teams to plan, work, or meet with faculty, or used formally for lectures and discussions on subjects useful to the teams to further their designs, such as just-in-time technical subjects, computer applications, or laboratory instrumentation and methods. For the golf ball quality control system, which required an electronic scale, technical lectures included information on strain gage measurement techniques, Wheatstone bridge circuitry, and signal amplification.

The fall 2000 Phase 2 project required students to design and construct a *pipe inspection device* which, after being inserted into the upper opening of a vertically mounted length of 3.75 in. ID

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pipe, would autonomously descend the length of the pipe, sense the lower opening of the pipe, return to the top of the pipe, and digitally display the value of the pipe length that it had measured in the process. Technical lectures included information on control logic, sensing, and length measurement. The corresponding Phase 1 project was the design of a device to crawl vertically within a pipe, the purpose of which was to familiarize the students with the issues related to such a device as a lead-in to the Phase 2 project.

The fall 2001 Phase 2 project was sponsored by Capital Marketing Technologies, Inc., a local medical products company – the first time that a Junior Design project has had an industrial sponsor. The company requested that the students design and construct prototypes for a device to quickly slit the backing-paper on medical adhesive pads. The purpose of the slit is to facilitate the ease with which a customer can peel the backing paper from the adhesive pad. Specifications included that the device must slit the backing-paper on adhesive pads of various sizes and shapes at a rate of 40 pads per minute and that the rejection rate (backing-paper not slit; adhesive pad cut or mangled) be less than 5 %. The corresponding Phase 1 project was the same project, but with a shorter development period, for the purpose of testing the feasibility of various concepts. A prototype backing-paper slicer is illustrated in Figure 2.

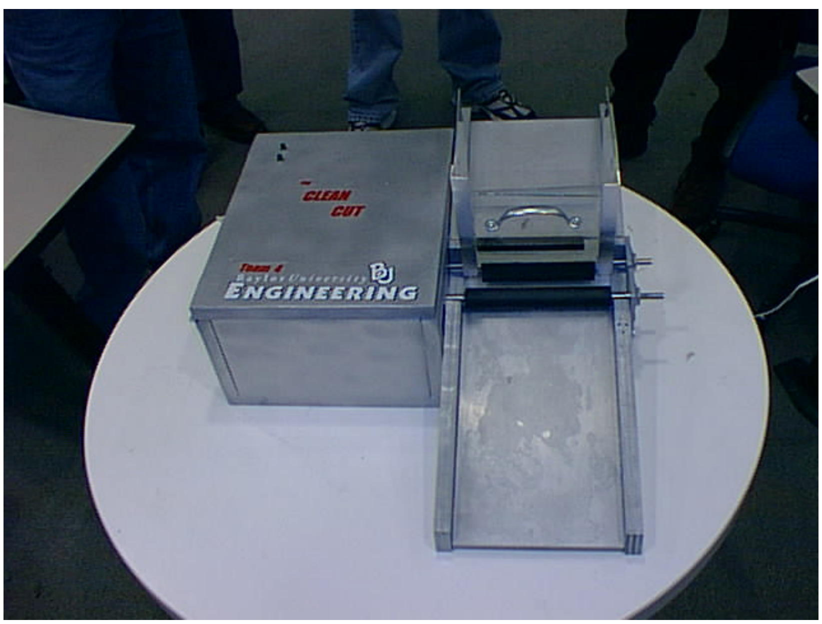

Figure 2. Phase 2 Prototype of Adhesive Backing-Paper Slicer.

Complete descriptions of past Junior Design projects, including detailed problem statements, can be viewed via a link on the webpage ecswww.baylor.edu/faculty/newberry

IV. Teams

Team size for the scale of projects used in Phase 1 and Phase 2 is 3-5 students. Students are assigned to teams by the faculty, insuring a balance of ECE, MEC, and EGR students on each team. Team assignments are typically changed between Phase 1 and Phase 2 to increase

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students' exposure to their peer (although the fall 2001 externally sponsored project was an exception due to a desire by the students to continue development of promising concepts from Phase 1). Early in the semester, the faculty conduct lectures and discussions on teamwork skills, team organization, and project management. Each design team is free to adopt an organizational model with which it is comfortable. At the end of Phase 1, at the midpoint of Phase 2, and at the end of Phase 2, peer evaluations are conducted in which each student evaluates each of his or her teammates with respect to several categories in the areas of engineering skills, contribution to the team, and professional conduct. Results of these evaluations are fed back, anonymously, to the students to foster their own personal growth. The results are also used in evaluating possible deviations of individual project grades from team project grades for cases where individuals have been identified as having made significantly higher or lower contributions than expected.

V. Communication Skills Development

Communication assignments cover oral, written, and graphical modes of communication. Both individual and team communication assignments are given. The team assignments, and some individual assignments, are directly project-related. Other individual assignments provide specific preparatory instruction and practice prior to project assignments.

Oral Presentations

- Career Plan Briefing: In the first week of the semester, each student is required to deliver a *career plan briefing*. This is a 2-3 minute, rehearsed presentation in which a student details his/her educational, employment, and leadership background and experiences, and discusses his/her career objectives. Professional dress is required and students must prepare one overhead transparency as a visual aid. Students are given prior instruction on oral presentation skills and on presenting one's self in a professional setting. As the first assignment of the semester, this presentation helps set the tone for the professional expectations for the course. In addition, it is an excellent vehicle for the students to begin to get to know each other. Instructors evaluate students' presentation skills and provide feedback via a detailed evaluation form, and students receive individual grades on the assignment.
- Phase 2 Team Presentations: During the Phase 2 project, design teams typically make 2 or 3 formal team briefings. There is typically a *conceptual design proposal presentation* near the beginning of Phase 2, a *preliminary design progress report* midway through, and a *final design presentation* at the end. Two or more team members deliver each presentation, with each team member required to participate in at least one presentation. These presentations utilize PowerPoint and are typically 8-10 minutes in duration. Instruction is given on the proper structure and content of technical presentations and on delivery techniques for multiple presenters. The grades for these presentations are team grades, so each team member has a stake in the preparation of the presentation, whether speaking or not. Detailed evaluation of a presentation, with respect to both content and mechanics, is provided to the team.

Writing – Individual writing assignments occur throughout the semester and are of several forms.

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- Design Notebook: Students are required to maintain a *design notebook* in which they collect all of the written documents for the course. These include handouts, class notes, journals, assignments, reports, team notes, sketches, drawings, etc. While not a specific *writing assignment* per se, the design notebook requires students to maintain and organize written documentation for archival purposes. The format for the notebook is specified and the completeness of the notebook is evaluated for a grade at the end of the semester
- Journals: During each week in which a design project is in progress, students are required to keep a daily journal (diary) about their activities related to the project, including total time spent. These journals are collected from, checked, and returned to the students on a weekly basis. The content of individual journals is not graded, but students do receive grades at the end of the semester associated with the completeness of their journals. The instructors record from the journals the amount of time devoted to the projects; this information is used for statistical purposes to track the relative levels of effort for various projects.
- Résumé: In conjunction with the career plan briefing, students are required to create and submit a professional résumé. Draft résumés are peer reviewed before the instructors evaluate final versions.
- Executive Summaries: Each student is required to submit two *executive summaries*, one at the end of Phase 1 and one at the end of Phase 2. These 1-2 page documents provide an individual perspective on the design experience for each of the projects. In them, students summarize the problem, the solution approach, the implementation, and the outcomes of the projects. These documents become the preface to the design notebook. Instruction is provided on the preparation of these documents. Instruction is also provided on editing, and, prior to final submittal, a class period is set aside for students to submit draft copies to their peers for review and editing.
- Description Writing: Since design reports require detailed descriptions, prior to the first project formal instruction is given on writing a description of a device or system. Students are then required, individually, to write a detailed description of a simple device (a stapler, for example). As with the executive summaries, students are required to submit draft copies for peer editing.
- Instruction Writing: The Phase 2 project typically requires a set of written instructions, or owner's manual, for the finished device. Therefore, prior to the start of Phase 2, students are given formal instruction on instruction writing. They then are assigned, individually, to write a set of instructions for a specified task (changing a car tire, for example). Students submit draft copies of these instructions for peer editing prior to final submission.

Team writing assignments occur in both Phase 1 and Phase 2 projects.

- Phase 1 Concept Description: Teams are required, before commencement of construction, to provide the instructors with a detailed written concept description (and corresponding drawings/sketches). This document is weighted equally with the resultant hardware for the Phase 1 team grade.
- Phase 2 Conceptual Design Proposal: Before commencing construction, Phase 2 teams are required to prepare a design proposal. This document includes a summary statement of the problem, a detailed description of the design concept (including appropriate drawings),

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and a plan for implementing the design. The latter will include such information as a detailed project schedule, a budget, a description of the team organizational structure, task assignments, and procurement plans.

- Phase 2 Preliminary Design Progress Report: This document, typically submitted midway through the project, provides an up-to-date description of the design (with revised detailed drawings), describes significant design changes or difficulties encountered, and provides revised project schedule and budget documents.
- Phase 2 Final Report/Owner's Manual: At the end of Phase 2, teams typically submit a final report in the form of an owner's manual for the prototype device. This document will include a detailed description of the device (with associated drawings), a set of detailed instructions for the operation, storage, and maintenance of the device, an itemized parts/materials list, and appropriate safety information.

<u>Graphical Communication</u>

- Individual CAD assignment: Prior to the Phase 1 project, students are given instruction on the use of CAD software (typically this is refresher information, since CAD is introduced in the freshman course). Students are then assigned, individually, to produce and submit a specified engineering drawing (practice drawing unrelated to projects).
- Phase 1 Concept Description: This document requires CAD assembly drawing(s) of the proposed design concept.
- Phase 2 Conceptual Design Proposal: This document requires CAD assembly drawing of the proposed design concept. In addition, the implementation plan requires graphical documents such as Gantt charts and organization flow charts, about which instruction is provided.
- Phase 2 Preliminary Design Progress Report: In addition to the types of graphical documents contained in the conceptual design proposal, this report would typically require detailed part drawings for parts that require in-house manufacturing.
- Phase 2 Final Report/Owner's Manual: In addition to the graphical documents associated with the previous reports, the owner's manual typically requires a series of specialized sketches/schematics and/or digital photographs to accompany the step-by-step instructions.

VI. Engineering Professionalism

Discussions of a variety of topics pertaining to engineering professionalism are interwoven throughout the semester. Some of these topics impact the function of the design teams in a direct way, while others are more general in nature. This study of engineering professionalism culminates in an *engineering professionalism exam* – the only examination given in the course. One or more class sessions are devoted to each of the following topics (approximately eight classroom hours):

- Working on a team: team dynamics and communication; team organization; problem resolution; conducting meetings
- Occupational safety in the design laboratory and workshop

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- Professional organizations, professional service, professional registration, continuing education
- Social impact of engineering: product liability, occupational safety and health, industrial safety, environmental protection, ethical use of technology
- Engineering ethics: ethical theory, ethical codes, state regulations, case studies

In addition to the formal class discussions of professionalism topics, the course is structured to model a professional environment throughout. The students are treated as *employees* placed into design teams within a *company*, with the instructors as the *supervisors*. The students initially seek *employment* via the résumé and career plan briefing assignments at the beginning of the semester. Students are thought to come to *work* rather than class. They receive one personal day (absence) during the semester and, in addition, receive *sick leave* for verifiable illness. Additional absences result in reductions in a student's final grade. Classroom lectures are thought of as *in-house company training and professional development*. Design project activities are *product development* activities. Design teams have access to a departmental machinist and a departmental electronics technician. Students are required to interact with these support personnel in a professional manner, providing appropriate drawings and schematics for work requested. Students perform three peer evaluations of their design teammates during the semester, providing each other, and the instructors, feedback on professional performance and demeanor.

VII. Grading

The grades for an individual student are separated into two parts: individual assignments and team assignments. Individual assignments include the career plan briefing, the individual writing and CAD assignments, and the engineering professionalism exam. Team assignments include design reports, design presentations, and hardware compliance tests. Each team member receives the same grade on team assignments. However, an individual's grades on team assignments may be adjusted at the end of the semester at the discretion of the instructors if warranted by the peer evaluations. The specific values assigned to each graded item vary slightly from one semester to the next, as do the number and nature of the items themselves, depending on the projects. Below, a typical grade breakdown is given (spring 2002 semester)

Individual Oral/Written/Graphical Communication	35 %
Engineering Professionalism Examination	8 %
Phase 1 Project – Team Grade (±peer rating)	14 %
Phase 2 Project – Team Grade (±peer rating)	43 %

Most written assignments require a preliminary draft to be submitted for peer editing before final submission to the instructors. In addition, the team presentations require dry-runs to be presented to the instructors before presentation to the class. The written drafts and dry-runs are not graded, but failure to submit/perform a draft/dry-run will result in a 15% penalty on the final product.

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VIII. Student Assessment

Students are asked to fill out a course assessment questionnaire at midterm and at the end of the junior design course. These are in addition to the standard course evaluation that the university conducts for all courses. While the university form focuses mainly on the quality of instruction, the course questionnaires administered by the faculty concentrate on the structure of the course and the design projects. The midterm evaluation allows the faculty to make corrections if there are concerns the students have – typically related to such items as scheduling, grading, access to tools and laboratories, or areas requiring more just-in-time instruction. The end-of-term evaluation provides feedback on student perceptions of learning outcomes, appropriateness and scope of projects, and recommendations for changes.

In particular, students are asked to describe important learning outcomes. Items most often cited as important outcomes include

- Realizing the difficulties associated with the detailed design and troubleshooting of mechanical and electrical systems
- Learning the details of the specific technologies needed for a particular project.
- Proficiency at computer aided drafting
- Experience with fabrication processes and the use of tools
- Learning to work with and depend upon other people
- Following the engineering process from concept to product
- Learning to communicate, both in formal ways and also informally within a team
- Learning time management skills
- Making decisions in the absence of complete information and making tradeoffs

Students also describe those aspects of the course they find most, and least enjoyable. Aspects of the course students frequently report enjoying include

- Working in teams
- Hands-on Experience
- Pride of ownership in a finished product

Aspects of the course the students frequently report not enjoying include

- Paperwork/writing
- Lack of experience/confidence with fabrication, or lack of appropriate tools for their specific fabrication needs.

The end-of-term survey also asks students to assess how large a contribution the junior design course has had in furthering their knowledge and abilities in the areas addressed by the A through K criteria of ABET 2000. The assessment is on a 1 – 5 scale, with 1 indicating *no significant contribution* and 5 indicating a *very large contribution*. Of the A through K criteria, the ones consistently receiving the highest average scores (between 3.5 and 5) are

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- Ability to design a system, component, or process to meet desired needs (4.7)
- Ability to function on multi-disciplinary teams (4.3)
- Ability to communicate effectively (4.1)
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (3.7)
- Ability to identify, formulate, and solve engineering problems (3.9)
- Understanding of professional and ethical responsibility (3.5)
- Ability to use a computer effectively (3.8)

Criteria receiving the lowest average scores (less than 3) are

- Recognition of the need for lifelong learning (2.7)
- Knowledge of contemporary issues (2.2)

In addition to feedback on the course obtained during and at the end of the course, there is a mechanism in place to obtain feedback at the end of a student's educational experience. On exit surveys given to graduating engineering seniors, the junior design course is frequently cited in response to both the item, "List two engineering courses you feel were most useful for your engineering education," and the item, "Describe one or two of your best experiences in the Department." While the course is challenging and time consuming, students tend to view it as a seminal experience in their overall educational process.

IX. Discussion

There are several heuristically deduced benefits that the faculty have discovered through the accumulated experience of offering the course. These can be divided into three main categories: technical and professional (covered here), and motivational (discussed in next section).

The students, most for the first time in their lives, get the experience of carrying an idea through from concept to physical reality. In the process of doing this, they obtain experience with fabrication techniques and practices, learn about materials selection, learn applications of various machine and electronic components, and learn troubleshooting skills. They also apply their previously gained knowledge of computer-aided-drafting to the creation of complete working drawings for their designs. These are all areas in which their technical/engineering skills are advanced.

Perhaps a greater benefit of the course lies in the development of the students' skills in many non-technical or professional areas. Of all the courses in the Baylor engineering curricula, this course provides the greatest concentration of opportunities to develop communications skills of all types, and blends and distributes the various types of communication in a holistic fashion by embedding them in the design projects. Speaking, journaling, technical writing, and archiving are all ongoing activities for the students during the semester.

Other professional areas emphasized in the course, in addition to the professional topics covered formally, are: teamwork skills, including leadership, conflict resolution, and critical evaluation of

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peer performance; project management skills, including adherence to deadlines and milestones, materials procurement, time management, and decision making such as concept selection and time-cost-quality tradeoffs.

X. Closing Observations

While development of the technical and professional skills discussed above are the main programmatic objectives of the course, and are aspects of an engineering education emphasized in the ABET 2000 criteria, the faculty that have been associated with this course over the long term believe that perhaps the most significant benefit of the course has less to do with topical educational outcomes, and more to do with the motivation, retention, and morale of the students. Students typically take the junior design course in the first semester of their junior year, having just completed a lower division battery of math, science, basic engineering science, and university core courses. The junior design course provides, at a critical juncture in the student's course of study, an opportunity to obtain a comprehensive experience of "being" an engineer.

The course has become a "rite of passage" among engineering students – those in the sophomore year looking forward to it with a mix of expectation and apprehension, and those in the latter part of the junior year looking back with satisfaction and accomplishment. Students typically invest an amount of time in the course that is higher than average for other courses carrying the same credit, often working together late into the night when deadlines are near. This time invested, spent mainly working with teammates, seems to create a communal bond among the juniors, who at the outset of the semester may only have been casual acquaintances, if acquainted at all. After the junior design experience, students appear to consider themselves as part of a community of engineers, rather than as students at the university majoring in engineering. If a feeling of belonging to a community – particularly one so closely associated with one's chosen career path – is beneficial to a student's academic performance, then the junior design course provides a medium through which to firmly establish that sense of belonging at the midpoint of the engineering educational experience.

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Jim Farison is Professor of Engineering and chair of the Department of Engineering at Baylor University. He joined Baylor in August 1998, after serving in Electrical Engineering (1964-96) and Bioengineering (1996-98) at the University of Toledo, including a period as Dean of Engineering (1970-80). His BSEE is from the University of Toledo, and MSEE and Ph.D. are from Stanford University. He is a registered P.E. (Ohio), a senior member of IEEE, ISA and SWE, and a member of ASEE (campus representative), ASME, SPIE, SME/MVA and NSPE/PEE. He has served as an ABET/EAC evaluator for IEEE. At Baylor, he is teaching in signals and systems areas and in design, and is engaged in an image processing project with medical and remote sensing applications.

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