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A Design and Assessment-Based Introductory Engineering Course*

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The Engineering Division at Lafayette College has developed an innovative assessment-based first-year engineering course which introduces the engineering method and design/problem-solving approach. The course goals are to improve student motivation and retention, stimulate interest in and build bridges to mathematics, sciences, and the humanities courses, and to teach the students about engineering and how an engineer solves problems. Our experience suggests that it is possible to teach first-year engineering students how to begin to think and function as an engineer even though they lack the tools and experience of the practicing engineer. Lecture and laboratory topics include the structured design/problem-solving approach, design methods, modeling, analytical methods and analysis, materials and failure analysis, graphics, data acquisition, and control systems. The unifying element of the course is the semester design project where teams of students design, construct, and evaluate a solution to a technical problem. A thorough assessment process is in place that has guided the evolution of the course and assured fulfillment of the course outcomes. This paper discusses the philosophy and structure of the course, course topics, laboratory exercises, semester design project, assessment methods, course evolution, course effectiveness, and resource and personnel requirements.

INTRODUCTION AND BACKGROUND

AN ONGOING EFFORT is being made throughout the academic community to improve the first-year engineering experience through the inclusion of a first-year engineering course. These improvements are generally aimed at: i) strengthening student skills, ii) developing a sense of community, and iii) initiating a professional development program [1–3]. The underlying motivation for instigating these improvements is to address the issues of student satisfaction and retention [4–6] and to initiate professional study earlier in the curriculum [2, 7–9]. These issues were important considerations in developing the ES 101 Introduction to Engineering course at Lafayette College.

Retention, while not a major problem for the Engineering Division at Lafayette College, is always a concern. Many of our students who leave engineering in their first year complain that engineering was not what they anticipated. Why were these highly qualified and motivated students disappointed by their first-year experience? Often pre-college students have participated in creative engineering-type activities such as design contests, science fairs, bridge-building competitions, etc. Many have also done ambitious technical projects on their own. To the entering enthusiastic student, engineering is a creative endeavor that involves invention/design using technical skills and gadgets. The disappointment occurs when the student begins an engineering program with expectations of similar experiences only to be barraged with a variety of difficult and seemingly irrelevant and unrelated courses. Even students who do not leave engineering are somewhat disillusioned by the rigor without the satisfaction of engaging in creative engineering activities.

Another problem results from the unfortunate fact that most students enter engineering programs with little idea of what engineering is or how a practicing engineer functions. In other professional programs such as medicine, law, or pharmacy, students have a basic understanding of the profession prior to entering the program. Engineering students do not have this basic understanding for two reasons. Firstly, engineering students start their professional education at a younger age than do students in fields with post-graduate professional programs. Secondly, while most pre-college students have observed or interacted with doctors, lawyers, and pharmacists, very few have spent time conversing with engineers. Most young people understand that engineers create and work with space shuttles, automobiles, computers, and other things technical. They do not, however, understand the engineering process. Thus, when a high-school student selects engineering as a profession, it is usually a decision based upon incomplete information. It is important for the proper motivation of students that they understand the profession, the available options and opportunities upon graduation, and what to expect in their education.

ES 101 was created and specifically designed to address these issues. The overriding course

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objective is to teach students the fundamental nature of engineering in the form of the engineering method and design/problem-solving approach. The course was built on the philosophy that first-year students can learn enough about these topics to be able to function as an engineer even without the tools and expertise of a practicing engineer [3, 7, 10, 11]. The traditional method of educating engineers is to teach many separate but essential skills then to have the students assimilate these skills as they proceed through their education. Our approach works the opposite way, by first teaching the students how engineers function then filling in their education with the missing pieces. The material taught in the course serves as a foundation and springboard for subsequent engineering courses by enlightening the students as to why they need the skills they will learn in subsequent courses. While design problem-solving skills are commonly taught in first-year engineering courses (3, 5, 6, 12, 13), it is the holistic, integrated, and focused philosophy and execution of course mechanics and the inclusion of the engineering method which takes this approach to a new level.

An important goal for the course was that it would be discipline neutral and all topics would be relevant to all engineering disciplines. At the same time it was desired that the course provide exposure to all disciplines so the students could make an informed decision as to the type of engineering they would like to study. The Engineering Division at Lafayette College offers a common first year, and ES 101 is required of all engineering students regardless of discipline. The students make a 'more informed' decision as to their specific engineering major near the end of the second semester.

The objective of this paper is to present the philosophy, goals, and structure of the Introduction to Engineering (ES 101) course developed and taught at Lafayette College. Included in this paper are the relevance and motivation for the course, and how it fits into the Lafayette Engineering program, specifically the common first year. The design/problem-solving approach is first defined, then the methods used to teach it to first-year engineering students are detailed. The presentation of the course structure includes descriptions of course topics, laboratory exercises, semester design projects, and how these elements fit together with each other, and the overriding course philosophy and goals. Course assessment activities are described in terms of goals, methods, and ABET outcomes. The role of assessment in the development, evolution, and evaluation of the course is presented.

Course goals

The following specific course goals were developed within the context of the primary objective and central issues discussed above:

- To introduce students to the engineering discipline.
- To introduce students to engineering design and analysis methods.
- To make clear to the students that an engineer must possess a variety of skills beyond technical competence, including 1) professional responsibility, 2) excellent written and oral communication skills, 3) the ability to work both independently and as part of a team and 4) creativity.
- To build bridges between the mathematics, science, and social science/humanities courses.
- To help undecided students select the engineering subfield that best matches their individual talents, desires and goals.

Most engineers would agree that the course goals listed above are essential to the engineering student. Not all first-year students would agree. The problem is compounded by the fact that the concepts they are learning in their math and science courses seem abstract, disconnected, and irrelevant. This situation occurs because most students are unable to recognize the value of these topics within their (incomplete) model of engineering. It was imperative that ES 101 address this dilemma. Simply emphasizing to students the utility of each topic is ineffective. How can topics which are perceived to be disjointed be shown to be essential pieces of the engineering method? Lafayette's answer was to provide a true engineering experience in the form of design projects which are directly supported by laboratory experiences and lecture topics in an attempt to build bridges between the natural sciences, mathematics, engineering sciences, and social sciences/humanities courses [7, 10]. The design projects require the *immediate* application of the laboratory and lecture topics from ES 101 *and* concurrent math/science/writing courses in order to make the material relevant to the students. This strategy closes the loop in the engineering education process.

Assessment activities

The very nature of introductory engineering courses makes their goals, structure, curricular fit and function, etc., difficult to define. These difficulties were further exacerbated by attempting to design just one course to suit all engineering majors. Therefore, from the initial conception of the course, assessment activities were considered to be an essential component of planning, improving and evolving the course, satisfying the major departments, best serving the students, and ensuring that all those affected by the course had an opportunity to comment officially. The assessment activities obviously also fulfill ABET 2000 requirements.

The course has many constituents to satisfy including the students, the course faculty, the rest of the engineering faculty, the major departments, and the Engineering Division. Each department was required to sacrifice one required course to fit ES 101 into their curriculum, so the cost of the course was high. Constant input and formal feedback from all constituents was considered necessary, not only for the good of the course, but in order that the course can fill the needs of each major department, and have the rigor and relevance demanded by the general engineering faculty.

The input, feedback, assessment, and data collection activities related to this course are broad and varied, and reach a variety of constituents. Furthermore, the assessment activities cover specific ABET outcomes as well as course issues and goals. The annual course assessment is conducted in three parts (see Appendix A, B, and C): an interview with a representative group of ES 101 students near the end of the fall semester, a written survey completed by all of the students enrolled in the course, and a written survey completed by visiting professional engineers who evaluated the final design presentations made by the student design teams. The results are shared with the current instructors, the future instructors, and the members of the Engineering Council. In addition, the course is reviewed periodically by a group of engineering faculty who take a much broader view of the course goals, structure, resource management, curricular benefit, etc.

ABET outcomes

The ES 101 course covers a wide area in terms of engineering topics and concepts. The case could be made that most of the pre-specified Program Outcomes are addressed to some degree in the course, as happens with most design-oriented courses. The following outcomes were selected not only for their relevance to the course content, but because the Engineering Division is interested in tracking the students' development in these areas as they progress through their engineering education:

C—An ability to design a system, component, or process to meet desired needs
D—An ability to function on multi-disciplinary teams
G—An ability to communicate effectively

These outcomes are self-assessed absolutely (student interview) and comparatively (written survey), and are externally assessed by visiting professional engineers. This three-part coverage provides various points of view and redundancy for these difficult to measure and quantify outcomes. The data is largely used for year-to-year comparisons and trend monitoring.

THE DESIGN/PROBLEM-SOLVING APPROACH

Students enter Lafayette's engineering program with widely varying abilities, experiences, and attitudes. However, there is much common ground, in that each student has engaged in creative activities, has an interest in technical matters, has solved problems, and has attempted design. What incoming students lack is the disciplined and structured approach of the engineer. Thus, students are taught the engineering methods and a well-structured problem-solving/design approach that breaks the process into orderly steps with an emphasis on logical progression through the steps. When selecting the design method to teach from the many available, an important criteria was that the method should be easy to learn and simple enough to avoid inhibiting the design process.

The approach chosen follows the outline suggested by Wales [14]. This approach breaks the design process into the following steps: 1) define the problem, 2) establish a quantitative goal(s) with constraints, 3) generate possible solutions, 4) evaluate solutions and select the best, and 5) take action through constructing, evaluating and modifying models, prototypes, etc. Similar approaches have been used at other institutions [2, 3, 13].

The design/problem-solving method of Wales is relatively straightforward to teach, but the actual process is less precise and must be learned and developed through actual design experience. Along with this algorithmic approach, design instruction must also emphasize that problem-solving and design are neither pure artistic creativity nor the rote application of equations and algorithms, but instead it is the development of solutions, applying what can be thought of as skilled art, built on the foundation of technical knowledge, engineering science, and experience. Thus, students learn that engineers must possess both creativity and strong analytical tools to be successful. Unfortunately, this type of thinking is generally new to the students, since problems presented in high schools are often carefully structured to produce a single correct solution. A realistic design experience causes confusion and frustration as students find that their well-developed and narrow problem-solving approaches do not work. The problem is too big, it involves unfamiliar disciplines, there are many variables, and there is no unique solution [9, 15, 16].

The semester-long design project was configured in such a way as to give the students a realistic and comprehensive engineering experience from problem definition through construction and evaluation, which provides a client, real or hypothetical, with a useful product or solution to a problem. This client-oriented project is similar to the project assignment given in the freshman engineering design course taught at Harvey Mudd College [17]. However, the ES 101 project includes a significant amount of modeling and analysis, all carefully structured and monitored throughout the semester.

For the semester design project, each student works as a member of a team responsible for designing, constructing, evaluating, documenting, and presenting their solution to a common technical problem. The project is structured so the following traits of the engineering profession are introduced and put into practice immediately in each student's academic career:

- Engineers generally work in groups.
- Engineering problems are open-ended and multidisciplinary.
- There is a well-defined approach to solving engineering problems.
- Engineering is a creative discipline constrained by the laws of nature.
- The borders between engineering disciplines are not rigid.
- Engineers learn from failure.
- Effective communication skills are essential for engineers.

The project teams are established by the faculty during the first week of the semester and consist of four or five students [12]. Using the results of a student survey, an effort is made to diversify each group in terms of gender, engineering sub-discipline, level of computer experience, and mathematical skill. The team approach offers the opportunity for students to experience group dynamics and to develop cooperative working skills [2, 3, 6, 7]. These educational components usually occur later, if at all, in traditional engineering curricula.

In the past, each student team was responsible for selecting its own technical problem within the context of a common theme. The theme, which changed yearly, provided a focus yet was broad enough to allow the projects to reflect the particular interests of the group members. Past themes have included the International Space Station, the transportation industry, and devices to aid disabled clients. This format resulted in very interesting and ambitious student projects. However, as the burden on the shop personnel was overwhelming, this approach was determined to be unsustainable and was subsequently abandoned.

The current format of the semester design project is to assign one common semester design project in the model of the Design and Manufacturing course offered in the Mechanical Engineering Department (19). Using this model and operating within the teaching block format (described later), design problems are devised with the following objectives and constraints:

1. There must be a design sub-component from each of the four engineering programs offered at Lafayette (chemical, civil and environmental, electrical and computer, mechanical).
2. Because the students do the blocks in different orders, the sub-designs must be physically and functionally independent of each other.
3. The overall design project must be assembled from the individual sub-design/sub-systems.
4. Each sub-design must be completed in the time allotted for each block (approximately three weeks).

Devising design projects to meet the above goals is difficult but not impossible. Table 1 lists a few of the more successful semester design projects and outlines the block sub-design components of each project. The common design project has greatly reduced the demands on the shop personnel, thus making the course more manageable. The students no longer select their semester design project, which diminished the experience for some. However, the majority of the students are highly satisfied with their design experience.

As an example, the Mechanical Engineering portion of the Weather Station semester design project will be described. The overall function of this project was to measure and record wind speed and air temperature over extended periods of time. The four sub-designs for the weather station can be seen in Table 1. Each of the sub-designs can be accomplished independently of the others. The project included structural, electrical circuitry, material selection, and data acquisition design activities which coordinated with the lab and lectures provided during the associated block. The final design was assembled from all the sub-designs plus various other components (see Fig. 1).

The Mechanical Engineering block portion of the project required the students to design and construct the truss support structure. The support structure connected the predesigned base plate with the electronics housing. The height of the

Table 1. Examples of semester design projects

Project	Mechanical	Electrical/Comp	Chemical	Civil/Environ
Weather Station	Aluminum Truss Support Structure	Temp and Wind Speed Data Acquisition Circuits, amplifier design	Component Material Selection for wind vanes and base structure	Data Acquisition Application
Desalination Pump	CNC manufacturing, linkage design	Pressure instrumentation, data acquisition	Reverse osmosis system design	Pressure vessel design, structural design
Temporary/Emergency Shelter	Power generation, CNC manufacturing, mechanism design	Lighting system design, circuit design	Material coating, polymer manufacturing, fermentation processes	Tent inter-structure design, water purification

Fig. 1. Weather station and desalinization pump.

structure was to be 6 inches (152.4 mm). It had to support a thrust load of 100 pounds (445 N) and a horizontal plane torsional load of 40 foot-pounds (N-m). The allowable deflection was specified as 0.5 inches (12.7 mm) in any direction. The entire structure had to be constructed from a 12-inch (304.8 mm) square sheet of 1/32 inch (0.794 mm) thick aluminum. The students were also supplied with a 24-inch (609.6 mm) long aluminum tube (0.5 inch [12.7 mm] in diameter and with 1/32 inch [0.794 mm] wall thickness). The students learned through lectures about the relationships between cross-sectional shape (flat, channel, round-hollow, I-beam, and T-beam) and load-carrying ability (tension, torsion, bending, compression). They also learned about the qualitative behaviors of trusses. From this new knowledge, they designed, constructed, and tested their structures.

The students are presented with the design project/problem at the beginning of the course. Where they begin depends upon which block they start with. The design process is the same, however. The students begin by generating possible solutions to their particular design sub-problem. They utilize their inherent creativity to brainstorm and are urged not to dismiss any ideas or criticize each other, as it inhibits the process. Students often feel that they need to start from scratch. However, there is continual emphasis that it is good engineering practice to build upon the work of others, use proven methods, and to borrow or evolve successful designs. The difficult step is for the groups to select the best design from their catalog of possible solutions. As is discussed in more detail below, the lecture and laboratory exercises provide the framework for many engineering approaches, design methods, and specific knowledge which can be applied to this part of the process. For example, the students are taught how to use a straightforward 2D finite element program for analyzing truss structures. Students have been successful in transferring this skill to the design and analysis of their proposed structures. The student groups present their preliminary designs, complete with supporting analysis, CAD drawings, and bill of materials.

For the students, physically realizing their designs is an essential component of the experience [3, 16, 18]. First and foremost, it allows the groups to evaluate and iterate their designs while learning from failures or shortcomings. Equally important, however, is the satisfaction and pride students derive from constructing their designs. In addition, this hands-on element provides students with the opportunity to interact with technicians and become familiar with common machine tools and manufacturing processes, basic mechanical and electrical components, and testing equipment. Once more, construction allows students to experience issues associated with manufacturing a design.

This process is repeated through each of the engineering blocks, after which the students have the four sub-designs constructed and tested. During the last week of the semester the students assemble their sub-designs together with any predesigned components to create the completed design. The complete project is then evaluated and/or applied to the initial design problem or application.

A final written and oral report documenting their design is presented during the last week of the semester. The designs and oral presentations are judged by practicing engineers. The evaluation criteria for the judges is presented in Appendix C.

Faculty interaction with students is crucial during all stages of the design process to ensure steady progress, to help the groups over rough spots, to monitor individual student participation, and to produce designs which can be effectively constructed, completed, and evaluated. During meetings it is important for faculty to focus an asking guiding questions rather than on providing solutions. Due to their lack of experience, students are quick to latch on to faculty suggestions instead of pursuing their own ideas. At times this 'hands-off' approach is difficult for the students to appreciate; however, it is crucial for a meaningful design experience.

Experience has shown that students have difficulty at three stages of the design process. First, they often struggle at the beginning, since many students are initially overwhelmed by the college experience and find it difficult to work with a group of strangers. The instructor's job is to help students overcome their initial fears and encourage lively discussion and input from all the group members. Secondly, students can tend to jump to the generation of ideas step without fully understanding the problem. The instructor must reign in the enthusiasm and make sure that groups invest sufficient effort in understanding the problem and related circumstances before moving on. Thirdly, students can have difficulty selecting and detailing the best design/problem-solving strategy from their list of preliminary ideas. It is at this point that their lack of engineering tools and experience causes the most problems, as they are not yet equipped with the necessary means for thoroughly evaluating their proposed designs.

COURSE STRUCTURE

This section describes the nuts and bolts of the course, including the course format, text, lecture topics, laboratory exercises, graphics labs, and human and computing resources. The course is required of all first-year engineering students (including the Bachelors of Arts (A.B.) engineers) and is offered in the fall semester. Class sizes are 34–40 students in each of four lecture sections, with each section split to form two 17–20 person lab sections. Each lab section is further subdivided into design teams of four to five students each.

The text used in the course is Introduction to Engineering which is a Prentice-Hall Esource book. The text is custom configured from portions of other texts and instructor notes. As is often the case for introductory engineering courses, no one text adequately meets the needs of the course. The Esource text format allowed the instructors to custom configure the course text to directly support all the course topics. The course is also supported by a course website. Students can receive assignments, announcements, and grades from the website.

Presently the course is structured in a block format. The four B.Sc. engineering disciplines offered at Lafayette College are presented in four successive blocks each being three weeks in length. The A.B. Engineering discipline is presented, in two parts, during the first week and final week of the semester. During each block the students are introduced to a different area of engineering, where they learn about the discipline, are taught fundamental engineering analysis and design methods, and are presented with design project specific information. The students then apply these methods of analysis and design to the group design project. Interspersed within these blocks are the engineering graphics lectures and labs. Each engineering block contains the following:

- 6 discipline-specific engineering lectures
- 2 discipline-specific engineering labs
- 2 graphics lectures
- 1 graphics lab and quiz
- 1 group design lab
- 1 discipline-specific engineering block exam

Lecture topics and laboratory exercises

The lecture topics and engineering laboratory exercises are structured to help students learn the engineering method and design/problem-solving approach, to introduce fundamental discipline-specific design and analysis methods, and to teach the basic engineering skills necessary to successful completion of their design project. The lectures and laboratories are coordinated with the sub-designs of the semester design project. The students are assigned individual pre-lab exercises and activities and submit a formal group report one week after the completion of each engineering lab.

The design/problem-solving approach is presented at the beginning of the semester and is reinforced throughout the individual blocks. On the other hand, the engineering method is more assimilated than directly taught. It is experienced in portions throughout the semester both in lecture and lab. The definition of the engineering method as taught in this course is the ability to create realistic and representative models of physical systems, then apply the appropriate engineering theory and equations to describe, analyze, and predict the behavior of the system. Implied in the definition is an understanding of the system behavior, the assumptions used to create the model, the differences between the model and the actual system, the limits of the engineering theory, and the reasonableness of the calculated results.

Along with the overall design process, the students are introduced to various specific design methods from trial-and-error evolution through optimization algorithms. Emphasis is placed on the use, development, and evaluation of models including analytical, computer, and scale models, all of which are applied in laboratory exercises. The importance of using proven designs is discussed, as is the role of failure in the design process. In addition to the design project, the structured design/problem-solving approach is demonstrated through classroom examples, case studies, and homework.

Various engineering examples from all disciplines are regularly brought into class for demonstration purposes during the opening minutes of lectures. The class opening demonstrations are designed to provide an active learning opportunity, to relate a course concept to a real-world engineering application or lab activity, and to serve as a lead into the lecture topic for the day. For example, prior to introducing the concept of variability in design, the lecture begins with each student using a multimeter to measure the resistance of a $100\,k\Omega$ resistor. The benefits of this simple example are many. Firstly, every student learns how to use a multimeter. Secondly, during the demonstration the function of resistors in electronic components is discussed and printed circuit boards containing resistors and other electrical components are passed around the class. Thirdly, the data collected serves as a basis for a statistical analysis performed later in the lecture.

There are a variety of laboratory experiences throughout the semester which are coordinated with the block lectures and semester design project.

The laboratory exercises change from year to year, with new instructors and different semester design projects. The labs presented below are recent and typical of the course. The links to the course objectives, design/problem-solving approach, and engineering method are highlighted.

Design Lab I: In this first design lab, student teams plan and construct the familiar balsa-wood bridge within prescribed dimensional and structural constraints. The objectives are: 1) to support the maximum loading, and 2) to achieve the highest strength-to-weight ratio. As a pre-lab exercise, the students design a truss using existing structures as guides, then employ a user-friendly 2D finite element package to model and predict the performance of their designs. During the lab, students compare the actual performance of their structure to its predicted performance and are asked to discuss and resolve any differences. Based upon these observations and new insights, they redesign and retest their structures. Many students have participated in this type of project before or are at least aware of it. This familiarity is an advantage, as the use of computer models to create designs and predict performance dramatically illustrates the difference between the engineering method and the hobbyist method which they most likely employed previously.

Materials and Failure Analysis: The goal of this lab is to give the students sufficient knowledge to select appropriate materials for their design project. The instructor demonstrates various material behaviors, such as temperature and strain rate effects, and ductile vs. brittle failure modes. Students use an Instron machine to determine the tensile properties of samples of steel, aluminum, polyvinylchloride, and acrylic. Students are introduced to failure analysis through macroscopic material surface evaluation and are shown numerous examples of failed components. This is done in the context of analyzing a failure to improve a design.

Design Lab II: The students are taught how engineers use theory, models and equations to determine behavior, make predictions, and create designs. Of particular importance is understanding the limits of engineering theory and models in predicting actual system performance. Pre-lab exercises include calculating the period of a pendulum and the resonant frequency of a cantilever beam and then comparing actual and predicted behaviors. The primary lab activity is the analysis and redesign of a stop sign subjected to aerodynamic loads. The students determine the first torsional natural frequency of a stop sign model and the wind speed at which resonance will occur. They verify and reconcile their analytical results with strobe and wind tunnel experiments. Based upon their findings and their understanding of the supporting theory, the students redesign, build, and test new signs. All proposed redesigns must have analytical justification based upon appropriate theory.

Process Control: This subject area deals with digital logic control of systems and processes via programmable logic controllers (PLC). Digital logic process control is of an interdisciplinary nature, and is suitable for a general introductory engineering course. The instructor introduces everyday control systems, the concept of feedback control, and various components including sensors and actuators. Digital logic or on/off feedback control is given in-depth coverage with logic control taught and programmed using ladder logic diagrams. The process control laboratory exercise mimics an industrial melting process for polymer molding, whereby solids (ice) at low temperatures are introduced into molten fluid (water) and then pumped into molds while the fluid temperature and level are maintained within prescribed limits. The students design and program via programmable logic controllers the logic which controls the process. Students are given a float, thermal sensors, a piston pump and various other sensors and actuators to create the control system. As a supporting topic students are taught simple DC circuit analysis, which they must employ to wire the PLC, sensors, actuators, and power supplies together.

Experimental Methods and Data Acquisition Systems: Students are introduced to several common methods of measuring physical quantities as well as methods for amplifying, conditioning, and capturing data. The lab activity is the design of the amplification circuitry using operational amplifiers for acoustic, temperature, and strain measurements. The sensors and circuitry are interfaced to data acquisition boards contained in dedicated computers. LabView is used to control the data acquisition process, calibrate the circuit, and collect, analyze, and store the data. Several of the semester design projects utilized just such data acquisition setups.

Graphics labs

The graphics portion of the course serves two purposes. Firstly, the labs provide the students with an introduction to engineering and computer graphics. Secondly, the topic supports the design project by teaching the students how to properly communicate a design so that it can be manufactured. There are six graphics labs, which alternate with the engineering labs. Topics include orthographic projection, dimensioning, tolerancing, sectioning, isometric and oblique pictorials, assembly drawings and schematics, and 3D wire frame models.

Resources

The success of the course depends heavily on having the necessary space, laboratory, and computer resources and, more importantly, personnel time and commitment. The course requires the use of several of the engineering laboratories, including manufacturing, material testing, fluid dynamics, and controls. Other lab and test equipment is often needed to support the semester design projects. In addition, there is a need for dedicated space to serve as a working area for the students to construct and evaluate their design projects as well as secure space to store their projects. Also, a fully equipped and networked computer facility is required for the graphics portion of the course and the computer lab. These resources are drawn from all the engineering departments, thus significant coordination, cooperation, leadership, and commitment are needed from the Engineering Division.

The staffing requirements include four faculty, one from each engineering department, one of whom serves as course coordinator. Each faculty member is responsible for one lecture section, two lab sections, and approximately eight design teams. There is one additional instructor who is responsible for teaching the graphics labs to all eight lab sections. In addition, there are an equivalent of one and a half full-time engineering technicians who are involved in helping students construct their semester design projects, and who assist the faculty with lab setups.

COURSE EFFECTIVENESS AND ASSESSMENT

The ES 101 course has been in place for ten years now and continues to be required of all B.Sc. and A.B. engineering students. The course enjoys strong support from the engineering faculty and the students have always rated the course and their instructors highly. Data show that over the period in which the course has been offered the retention rate of engineers from the first semester to the second semester is 97.4%. Prior to implementing ES 101, the retention rate for engineers entering their junior year was approximately 68%. The most recent data show that this rate has increased to 79% when the introductory course is required. In addition, participation in discipline-related activities such as membership in student chapters of engineering societies, lunchtime professional presentations and faculty-directed research programs has noticeably increased. Interviews with students selected at random at both the conclusion of the course and at the end of the first year have provided favorable feedback. The students repeatedly stated that they had a much better understanding of the various engineering disciplines than prior to the beginning of the semester.

Other benefits of the course identified by the students include: an enhanced understanding of the importance of mathematics and science in solving engineering problems, the improvement of critical thinking skills, the continued development of both written and oral communication skills, and the value of teamwork. The three annual assessment tools have provided verification that the introductory engineering course is effectively meeting the course goals and ABET outcomes for which it was designed.

The structure of the course has undergone two major revisions since its inception. First, the design project has been changed from a format where the students select their own project within the context of a main theme, to a format where the design project is the same for all student groups. Feedback from the course instructors, students, and engineering technicians resulted in this change. The change has resulted in focused and manageable design projects, a reduced load on the engineering shop, and a more uniform design experience for the students.

The course also changed to a block format where the instructors cycle through the sections teaching only their discipline-specific material. Previously, each instructor was assigned one section and was responsible for all the course material. This change was motivated from instructor feedback indicating that teaching material outside their major department was overly demanding and uncomfortable. This change has eased faculty burden and increased faculty satisfaction considerably. Student response has indicated no major negatives with the change. However, some students expressed disappointment with not being able to get to know any one faculty member well. Also, the students who were sure of their engineering major did not always appreciate study of material outside of their major field. This reaction is tempered somewhat by teaching concepts such as design, data acquisition, materials, etc., which are important to all engineering disciplines.

While these two changes significantly affected the structure of the course, student satisfaction remained high and no effect was seen on retention. In fact, student opinion of the course continues to improve as the course is refined. More minor changes include making the graphics laboratory mostly self-paced, adding extra block and graphics lectures, and including evening 'Professionalism' and informational lectures.

Most course changes and refinements have resulted from information obtained during the assessment processes. The student interview coupled with instructor feedback prove to be the most useful tools for obtaining this information. The student surveys are most useful in determining the effectiveness in meeting the ABET outcomes. The relative measures presented by the data are most useful for ranking relative growth in student abilities, thus targeting future efforts and modifications. The external assessment tool has so far mostly validated our efforts. This tool may be modified or dropped in the future.

DISCUSSIONS AND CONCLUSIONS

This paper presented the philosophy, goals, and structure of the Introduction to Engineering course developed and taught at Lafayette College. Highlighted in the paper are the course topics, laboratory exercises, semester design project, assessment methods, course evolution, course effectiveness, and resource and personnel requirements.

As has been the case at many engineering schools, Lafayette's first-year engineering course was created to introduce students to the discipline, teach basic engineering skills, and improve student retention. In addition, the course was designed to teach students about engineering and how engineers function, to provide a meaningful design experience, stimulate interest in non-engineering courses, and enhance student communication and group interaction skills. A common shortcoming of many introductory courses is that they underestimate the capacity of entering students to understand the engineering method, function as engineers, and engage in actual engineering activities. Such courses may be perceived by students as simplistic, uninteresting and of little value to their education. As a result, many institutions drop their introductory course after a few years. Such was the case with Lafayette's first attempt at an introductory engineering course. From the beginning of the development of ES 101, it was clear that the course must have a higher expectation of student capabilities, and students must participate in relevant, meaningful, and challenging engineering experiences if the course was to meet its goals.

The fundamental approach applied to this course is teaching the engineering method and the design/problem-solving approach in the belief that these skills represent the essence of engineering. We are convinced that it is possible to teach first-year students how to think and function as a engineers even though they lack the tools and experience of the practicing engineer. Taking this view of first-semester engineering students means that this course expects more from them; however, it provides a better educational experience. This approach has the advantages of immediately engaging the students, conveying the importance of their engineering science and non-engineering courses, making sense of their curriculum, and most importantly giving relevance to the separate engineering topics they learn later in their education. For example, concepts such as free-body diagrams, the accuracy of analytical methods, equation derivations, etc., have a place in the engineering 'big picture', since students have already applied these concepts to solve problems and accomplish design.

The emphasis on laboratory activities helps avoid the trap of many introductory courses by giving immediate application to the topics covered in lecture. The labs demonstrate useful engineering tools and the students were successful at assimilating the lab material to assist with their semester design projects. In addition, the labs served as mini design and/or analysis projects throughout the course. Although the primary motivation of the labs is to support the course topics and design project, they were also effective in providing exposure to the equipment and laboratory facilities of the different engineering departments.

The semester design project continues to be the highlight and unifying component of the course. This type of complete 'design, construct, and iterate' exercise represents a true engineering experience and is an effective method for learning the engineering process. Initial doubts concerning the ability of first-year engineering students to be effective designers have been dispelled as the students continually demonstrated that they can synthesize the material and methods taught in lecture and laboratory, learn and apply fundamental engineering theory, and are sufficiently intelligent to understand the performance behavior of standard off-the-shelf components. Students do, however, have problems at some stages in the design process. These difficulties most often stem from uncertainty as to what to do 'next'. Their instincts are generally good, but a lack of confidence and experience often halts their forward progress. Coaching from the faculty, usually done at the weekly design meetings, helps the students through these sticking points. As the students attempt to improve their designs, they eventually reach their analytical and technical limitations, which gives them additional justification and motivation for taking mathematics, physics, chemistry and engineering science courses. The students' interest, motivation, and enthusiasm, coupled with the willingness of the faculty to provide individualized instruction, has led to exceptional results, as the quality and scope of the student designs have far exceeded our expectations.

Regular assessment activities via varied assessment means have proven to be an invaluable component of the course. Significant course improvements have resulted from assessment-based feedback. In addition, the assessment has shown that the course is successful in meeting its goals and ABET outcomes. The many constituents plus varied methods of assessment such as absolute and comparative self-assessment, external assessment, and faculty review provide various points of view and redundancy for these difficult to measure and quantify goals and outcomes. The course goals and outcomes data are largely used for year-to-year comparisons and trend monitoring.

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APPENDIX A

Student Interview Questions

1. As a result of completing ES 101—Do you have an understanding of what engineering is all about and what engineers do?
2. Would you consider ES 101 to be a demanding course? How does the workload compare to your chemistry, calculus and FYS courses?
3. As a result of having a semester of ES 101, do you understand the similarities and differences among the engineering disciplines at Lafayette (A. B. Engineering, Chemical, Civil & Environmental, Electrical & Computer, and Mechanical Engineering)?
4. Do you understand the importance for engineers to function as team members? Did the course help you to learn to work as a member of an engineering team?
5. During the course of the semester, did your communication skills, both written and oral, improve?
6. What did you think of the design project? Was it challenging? Was it fun? Do you understand how to do design?
7. Did you receive timely feedback regarding your performance on tests and laboratory exercises?
8. What suggestions do you have to improve the course?
9. How many of you now know what your engineering major will be?

APPENDIX B

First-Year Engineering Student Survey

Issue 1. Please compare your ability to function as a team member in the solution of a meaningful open-ended design problem at the beginning of this semester and today.

Time	**Poor**	**Below Average**	**Average**	**Above Average**	**Excellent**
Start of Course					
Today					

Issue 2. Please compare your level of understanding of engineering design at the beginning of this semester and today.

Issue 3. Please compare your level of understanding of the nature of the various engineering disciplines represented at Lafayette (A. B. in Engineering and B. S. in Chemical, Civil, Electrical and Computer, and Mechanical) at the beginning of this semester and today.

Issue 4. Please compare your level of understanding of the role and importance of math and science in engineering at the beginning of this semester and today.

Issue 5. Please compare your level of comfort and experience with technical writing skills at the beginning of this semester and today.

Issue 6. Please compare your level of comfort and experience with oral presentation skills at the beginning of this semester and today.

Issue 7. What else should the faculty know about your experience this semester? Is there something else that you have learned that you believe is important? Is there something that you think you should have learned but didn't? How can we improve the student experience during this semester in the future?

APPENDIX C

External Assessment

Issue 1. How would you rate the students' ability to make an oral presentation?

☐ Poor ☐ Below Average ☐ Average ☐ Above Average ☐ Excellent

Issue 2. How would you rate the students' use of presentation aids (software, slides, overheads, PowerPoint, etc.)?

Issue 3. How would you rate the students' knowledge of basic engineering concepts?

Issue 4. How would you rate the students' ability to design a system, component, or process to meet desired needs?

Issue 5. How would you rate the students' ability to function as a member of a design team?

Issue 6. Please use the reverse side of this form to provide a short written assessment of the semester-long design project completed by the students.

Comments (including strengths and suggestions for improvement):