

Keeping the “General” in General Engineering: Designing Multidisciplinary Courses for the First Year of Engineering

Benjamin L. Sill, Matthew W. Ohland, Elizabeth A. Stephan
General Engineering, Clemson University, Clemson, SC 29634

Abstract

The General Engineering program at Clemson University teaches two courses required for all students planning to major in engineering. The first course, *Introduction to Engineering*, focuses on presentations and tours by each of the engineering departments. During the past year these presentations have become more active. The second course, *Introduction to Engineering Problem Solving and Design*, teaches a variety of skills fundamental to engineering. Since these courses address multiple disciplines, it has been a challenge to represent the content and perspective of all eight engineering programs offered at Clemson.

This paper describes recent changes in the General Engineering curriculum designed to improve the multidisciplinary character of these courses. In the first-semester course, some participation by technical disciplines outside of engineering helps to communicate the multidisciplinary context of engineering. Various approaches are being used in the second-semester course. These include identifying the learning objectives of the curriculum, restructuring exercises around these objectives, and engaging faculty from the engineering departments in the design of new activities and content. Changes to *Introduction to Engineering Problem Solving and Design* are catalyzed by an NSF grant to study the benefit of using real-time sensors in the curriculum. These sensors can measure a wide range of phenomena, facilitating the study of process variables and approaches that were previously difficult to include.

What first-year students know about engineering

What first-year students think they know about engineering

At summer orientation sessions, we ask incoming first-year students why they chose engineering as a major. The responses we hear include “I was good in math and science in high school,” “I have a relative who is an engineer,” and “I want to have a career where I can make a lot of money.”

When we follow that up by asking the same group what an engineer does, the most common response is a blank stare. If we do get answers, a few are reasonable while others miss the mark badly. Clearly, the students come to us more aware about certain disciplines. If we ask these students what a mechanical engineer or civil engineer or electrical engineer does, the responses, while varied, indicate that there is some level of basic understanding of these disciplines. If, on the other hand, we ask these same students what a ceramic engineer, a biosystems engineer or an industrial engineer does, there is much uncertainty.

Students come to us particularly ill-equipped to offer any kind of explanation as to what is characteristically “engineering”—that is, what the various engineering disciplines have in common. They see the different majors in engineering as being as isolated subjects, without much sense of the rich interface that exists where disciplines overlap. The multidisciplinary nature of engineering is nearly completely unknown to them.

Clemson and its General Engineering curriculum

Clemson University is a land-grant institution located in rural upstate South Carolina. Its population of approximately 14,000 undergraduates is drawn largely (65%) from in-state high schools. Originally a technical school, Clemson is still considered to be largely technically oriented, and the College of Engineering and Science is the largest college in the University. Clemson’s General Engineering program has coordinated a common first-year engineering curriculum since 1985.¹ The program was known as Freshman Engineering until 1993.

In 2002, our freshman class of about 800 in engineering had an average SAT score of over 1240. Our students are generally quite capable and most are hard workers. Despite this, about one in eight did not have high school physics. Further, about 25% did not qualify to begin directly in our Calculus I course. Our second semester Engineering Problem Solving and Design course (ENGR 120, 3 credits) requires Calculus I and Physics I as co-requisites. This course consists of both lecture and lab periods. Our first semester course (ENGR 101, 1 credit) focuses on providing students with an understanding of the various majors in the College of Engineering and Science. This course is described in greater detail elsewhere.^{2,3}

Clemson University uses a general first year to provide information that will help our new engineering students to select the most appropriate engineering discipline for them. Students do not have to select a specific major until the end of their first year. During their freshman year they are in General Engineering and all of them take the same required courses (chemistry, calculus, English composition, physics, and engineering). The General Engineering Program is staffed with professional advisors to assist students with their questions and concerns.

Assessment of our students indicates that about 50% change their mind about their intended engineering major (assuming that they had selected one when they arrived on campus) during their first semester. Another 15% or so change their mind during the second semester. These are some of the reasons why a general engineering program facilitates the transition to the university. We have found that a “general” first year is of substantial benefit to the students (and to the

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parental stress levels). It provides a time of maturing, a time to learn more about the various possible careers, and a time to adjust to college life without having the worry of “Have I selected the right engineering major?”

The objectives of our General Engineering Program are two fold: 1) help our students to make an informed choice of major, and 2) help our students to obtain a basic understanding of engineering and the design process. This is not easy! It must be done in a way that does not put too much emphasis on any one discipline, since the students are not in a major yet, and it must be designed to a proper level. This paper addresses some of the challenges, specifically: student preparation, differences among the majors, course content, and hands-on activities such as design projects and lab exercises.

The General Engineering faculty members have broad disciplinary expertise, which is of significant benefit in the incorporation of multidisciplinary activities.

- General Engineering Director Ben Sill has a PhD in Aerospace and Ocean Engineering and has taught most of his career in Clemson’s Civil Engineering department.
- Bill Park, Associate Professor, has a PhD in Electrical Engineering and regularly teaches courses for the Electrical and Computer Engineering department.
- Matthew Ohland, Assistant Professor, has a PhD in Civil Engineering, MS degrees in both Mechanical Engineering and Materials Engineering. His educational research frequently involves techniques from Industrial Engineering.
- Beth Stephan, Instructor, has a PhD in Chemical Engineering
- In addition to these faculty, students were hired in summer 2002 to support the development of curriculum materials to engage students of all disciplines. The students were from Biosystems Engineering, Ceramic and Materials Engineering, Chemical Engineering, and Electrical Engineering.

The preparation of first-year engineering students

For our courses to meet their objectives, we must move the student forward without expecting preparation beyond basic calculus and introductory physics. It is also important to include topics that will be useful no matter which engineering major they may select. Through experience, we have learned the most common skills and knowledge where students need further preparation before they are ready to advance in the engineering curriculum:

- How to draw a graph properly including the use of logarithmic scales
- How to sketch and interpret a graph of a physical process
- How to find fundamental dimensions of a quantity and relate units and dimensions
- The utility of non-dimensional representations
- How to take and analyze data and how to calibrate a system
- How to use spreadsheets including the use of conditional statements
- How to solve open-ended problems

- The experience of the design / build / test process
- Elementary statistics and the sketching of frequency distributions
- How various distribution parameters describe population behavior
- How teams function or how to do team projects
- How to make presentations
- What engineering is / how different engineering disciplines identify themselves
- The importance of professional ethics

Our courses focus on developing and strengthening these skills.

Differences among the majors

Engineers are about solving problems. Engineers are about designing things. Engineers are about making the world more livable. While we want students to learn that the engineering disciplines enjoy these similarities, we also have the responsibility to highlight the differences among the various disciplines, in order to help the students make a choice of major. In doing this, we face a variety of challenges. One of these challenges is finding a design project that allows students to focus on a discipline in which they are interested without overwhelming the students with a project that is impossible to complete. Table 1 summarizes some of the differences that provide a challenge in course development.

Table 1. Student awareness, program size, and ideal project emphasis for engineering programs.

Engineering Disciplines	Student awareness / knowledge	Program size	Ideal design project emphasis*
Biosystems	very low	small	M
Ceramic/materials	low	small	M,Ch
Chemical	medium	medium	Ch,P
Civil	adequate	large	M
Computer	adequate	medium	E
Electrical	adequate	large	E
Industrial	low	small	P
Mechanical	adequate	large	M

*Ch = chemical, E = electrical, M = mechanical, P = process

In addition to the various project expectations of each discipline, the different disciplines have needs that vary due to the typical awareness and knowledge of the discipline by the incoming students and the program size—how many students each major wants / can accept.

Some of the most challenging issues in course development are:

- 1) Providing adequate information about the programs that are less well known without shortchanging the better-known majors.
- 2) Developing design projects that cover a wide range of disciplines and yet are truly first

year projects. How much “spoon feeding” with respect to theory should be provided?

3) Selecting course topics that are useful in all the disciplines.

An overarching issue is to include ABET’s Criterion 3 Outcomes in the development of our courses. The outcomes that we have found most appropriate are:

- ability to *design and conduct experiments* as well as *analyze and interpret data*,
- an ability to function on multi-disciplinary *teams*,
- an ability to *apply knowledge of mathematics*, science, and engineering,
- an ability to *design a system*, component, or process to meet desired needs,
- an understanding of *professional and ethical responsibility*,
- ability to use *modern engineering tools*,
- ability to *communicate effectively*.

We have tried to include these in our courses in such a way that our courses support all of the engineering disciplines at Clemson University.

Course content

Specific course content has been developed by combining the list of needed preparation items (see comments regarding student preparation above) with the ABET Outcomes. The students are required to:

- Design experimental programs
- Take and analyze data
- Calibrate a system
- Solve open-ended problems
- Complete the design/build/test process for several major projects
- Function on teams

The primary academic topics that are included in this process are:

- Graphical solution to problems
- Dimensional analysis
- Extensive use of spreadsheets
- Introductory statistics

The sections that follow provide details as to our strongest efforts to cover these areas while helping the students to get a glimpse of the multidisciplinary nature of engineering.

Design projects: Minidesigns

Introduction to Engineering (ENGR 101), and more recently, Introduction to Engineering and Science (CES 101) is a single credit course and most of the class time is spent on an exploration of the various majors. The students are required to complete three “Minidesign” projects. As the name suggests, these team projects are of about a four week duration and do not require major design or construction efforts. They are, however, open ended to the degree that the teams are left to their own devices in solving a particular problem. Examples include:

Tree Height

Teams are asked to determine the height of a particular tree on campus. To receive full credit they must complete this task in three different ways. Climbing the tree is NOT allowed! It has been surprising the many ways that students have accomplished this task: throwing balls, taking photographs, raising a balloon, various geometric methods, and others.

Extinguish a Flame

After saying “Go!” the team’s design must extinguish a candle flame after a specified time period. A penalty is imposed for every second they are in error.

Surface Area of a Potato

Student teams must measure the surface area of a potato. Full credit is given if this is done more than one way (results are compared).

Of the many different Minidesign projects that have been used, *Extinguish a Flame* has yielded some of the most multidisciplinary contributions from the students. Student teams have created candle extinguishers that appear to represent solutions from the widest variety of disciplines.

Various teams

- used mechanical devices that mashed the candle wick
- poured sand or water on the candle
- covered the candle with a container to starve it of oxygen
- lowered the candle itself so as to submerge it in water
- activating a fan to blow the candle out

Design projects: Semester Projects

Design projects assigned in Engineering Problem Solving and Design are more substantial. Each of the two projects covers about half of the semester. While not every project can include mechanical, electrical, chemical, and process parts, attempts are made to allow inclusion of more than one broad discipline. The broad disciplinary expertise of the General Engineering faculty is of substantial help in developing design projects that allow inclusion of several different disciplines. Several recent examples help illustrate this.

Project I: Sticky Business

Students are required to design, construct and test a “bridge” out of Popsicle sticks. This is a rather common exercise, even at the high school level. We have, however modified this project to broaden it, and include more disciplines. These projects are graded on design performance and each team must make a final oral presentation. The project specification is summarized as:

A bridge, spanning a 1-foot gap is to be designed and prototype tested for load capacity, per the specifications outlined below.

Specifications:

Construction materials are limited to 1) Popsicle sticks, and 2) glue

Note: 500 sticks will be provided to each team.

Note: The glue must conform to the specifications below (you are to design your own adhesive). Limits:

a) No commercial product intended to bond things together such as adhesives, tape, caulk, etc may be used

b) No sticky foods, such as gum or melted candy, may be used

Critical (most highly desired):

The bridge uses 30 or fewer sticks

Bridge spans an open distance of 1 foot

Bridge is not clamped to the supporting surface

Bridge must be ready to be loaded within 30 seconds of placement over the span

Each team must be able to predict failure load to within 15%

Important (highly desired)

Bridge supports at least weight equal to two full soda cans

Golf ball can be rolled across the bridge

Bridge must provide at least 5 seconds warning time before failure

Desirable

Bridge is visually appealing

Target Load

Bridge weight will be measured in ounces and failure load in pounds. Failure load to bridge weight ratio should exceed 10.

Bonus

3-point bonus for any bridge whose ratio exceeds a value of 20

2-point bonus for team with highest ratio in the class

The project is easily graded using the sheet below simply by placing X's wherever the project earns them. This has been developed to allow students to assess how they stand as they design and test their project and to facilitate instructor grading.

Project Grading

This device performance is evaluated from a maximum of 40 possible points.

<i>Specifications</i>	<i>Critical</i>	<i>Important</i>	<i>Desirable</i>
1. Uses 30 or fewer sticks			
2. Bridge adequately spans one-foot gorge			
3. Bridge not attached to supporting surface			
4. Bridge equipped with loading capabilities			
5. Bridge ready to load within 30 seconds			
6. Failure load predicted within 15% or 1 lb			
7. Bridge supports two, 12-ounce can of soda			
8. A golf ball can traverse the bridge deck			
9. Bridge provides minimum warning of 5 s			
10. Bridge is visually appealing			
<i>Summation of Criteria</i>			

$$\text{Grade} = \left\{ 5 * \sum (\text{crit.}) + 3 * \sum (\text{imp.}) + 1 * \sum (\text{des.}) \right\} \left\{ \frac{\text{Load}[\text{lb}]}{\text{Bridge}[\text{oz}]} \right\}^{0.125}$$

Performance

Bridge Weight [oz]: _____

Prediction Load [lb]: _____

Actual Load [lb]: _____

Ratio load / bridge: _____

Is ratio of load / bridge > 20? Yes = + 3

Is ratio of load / bridge > all other teams? Yes = + 2

To calculate score: sum checks & perform equation operations; then add any bonus points

Performance Score: _____

This project incorporates both mechanical and chemical aspects. Students must develop a good mechanical design and of course the strength also depends on the quality of the glue developed. Some of the better designs weighed less than an ounce and supported a load of over 60 pounds. The ability to predict the failure load requires testing of multiple specimens and the need for quality control on the product.

Project II: Saving Timmy from the Well

This project allows students to utilize both mechanical and electrical devices. Previous projects have incorporated springs, levers, motors, pulleys, helium balloons, magnets and other devices. Overall this project is organized and graded in a manner similar to the previous one. Note that programmable devices are excluded (to prevent simply purchasing a device that will do the job, thereby circumventing the design process). As before, the completed design must perform adequately and each team must give a final presentation as a part of their grade.

Project Goal

Remove an object of your choice from the container provided. The container is a small (less than 2 inches in diameter) plastic lab bottle with the top cut off so that it is cylindrical (and approximately 3 inches tall).

Specifications

The following specifications must be met in the design. The specifications are grouped according to their importance in the design from the client's viewpoint.

Absolute (if your design doesn't meet ALL of these criteria, it will not be graded):

- The following equipment restrictions apply:
 - No programmable devices
 - No combustion of any sort
 - No voltages in excess of 12 volts
 - No energy may be added to the system (pushing, pulling)
- The apparatus must have a 1-foot by 1-foot footprint
- The object to be removed must begin the process resting on the bottom of the container and can be not larger than $\frac{3}{4}$ of the height of the container, i.e., it may not extend above the container.

Critical:

- The apparatus must remove the object from the container within 2 minutes.
- The apparatus must begin the process outside of a 2-foot square area surrounding the container.
- The object must finish the process outside the container.
- The object should be raised a height equal to that of the container at some point.

Important:

- The apparatus removes the object from the container in under 90 seconds.
- The object finishes the process outside a 2-foot square area surrounding the container.
- The object is raised a height of 1-1/2 times the height of the container at some point.
- The container is not modified in any way.
- The container is not made stationary (taped down, weighted down)

Desirable:

- The apparatus removes the object from the container in under 60 seconds.
- The object finishes the process outside a 4-foot square area surrounding the container.
- The object is raised a height of 2 times the height of the container at some point.
- The container finished the process in the exact same position as it began.
- The apparatus finishes the process outside a 2-foot square area surrounding the container.

Other comments:

- Compressed air will be allowed if supplied by a hand-operated bicycle pump.
 - Pre-manufactured compressed air cylinders of any type will NOT be allowed.
- The apparatus may be adhered to the floor; however, it must be removed at the end of the demonstration without causing any damage to the floor.
 - For example, suction cups are allowed; bolting the object to the floor is NOT allowed.
- Everything placed inside of the container will be considered as part of the object.
- The object can be made from any material of your choice.
- Multiple objects are NOT allowed; no extra credit will be given for removing more than one object.
- The use of phase change is NOT allowed.
- The use of a crank or any device that supplies continuous energy through interaction from any team member is NOT allowed.
- Solenoids, electromagnets, and multiple switches are allowed.
- Initially, the team will be allowed to activate the device in some manner – cutting a string, flipping a lever, throwing a switch. After time begins, however, the team will be forbidden to touch the apparatus, container, or object in any way.
- The container will be placed in the center of a square 2-foot on a side in the hallway outside of the project lab for testing. Any area determinations mentioned above include the air space above the 2-foot square, reaching to the ceiling.

Target Load:

The ability to meet the design criteria will be weighted by the rank obtained compared to the other designs submitted within this class. The apparatus weight, measured in pounds, and the object weight, measured in ounces, will be used to form a ratio of apparatus to object weight. When all testing is complete, the ratios will be ranked in descending order. This means the smallest apparatus to object ratio will be ranked as one; this will give the heaviest object moved by the lightest apparatus. Please refer to the attached performance matrix for more details.

Bonus:

If all the critical criteria have been met, the following bonuses may be awarded:

- A bonus of 5 points will be awarded to any team that can remove the object from the container without the container moving visibly. In addition to meeting the critical criteria, the container cannot be fastened to the floor to achieve this bonus.
- A creativity bonus of up to 10 points maximum may be awarded at the instructor’s discretion.

Number of Trials:

On testing day, up to two trials may be attempted without penalty. An additional three trials may be attempted (for a maximum of 5 trials), at a deduction of 5 points per additional trial. The last trial attempted will be recorded.

Object Weight [oz]: _____ Apparatus Weight [lb]: _____

Ratio apparatus wt / object wt: _____ Class rank: _____

Number of trials: 1 2 3 (deduct 5 points) 4 (deduct 5 pts) 5 (deduct 5 points)

Was the object removed from the container without the apparatus touching the container? Yes = + 5

Additional containers required? Yes No If yes, how many? _____ Deduct 5 points per container

Creativity Bonus – awarded at instructor discretion 1 2 3 4 5 6 7 8 9 10

To calculate score: sum checks & perform equation; then add any bonus points and subtract any deductions

Performance Score: _____

Individual grade

Device Performance will be evaluated from a maximum of 40 possible points, not including bonus points. This team score will be adjusted individually by peer evaluation.

<i>Specifications</i>	<i>Critical</i>	<i>Important</i>	<i>Desirable</i>
11. Apparatus starts outside of a 2' square surrounding container			
12. Apparatus ends up outside a 2' square surrounding container			
13. Move object to outside of the container			
14. Move object to outside of a 2' square surrounding container			
15. Move object to outside of a 4' square surrounding container			
16. Complete all tasks under 2 minutes			
17. Complete all tasks under 90 seconds			
18. Complete all tasks under 60 seconds			
19. Raise object to height of container			
20. Raise object to 1-1/2 times height of container			
21. Raise object to double height of container			
22. Container is not modified in any way			
23. Container is not made stationary in any way			
24. Container ends time in same exact position as it began			
<i>Summation of Criteria</i>			

$$\text{Performance Grade} = \left\{ 5 * \sum (\text{crit.}) + 3 * \sum (\text{imp.}) + 1 * \sum (\text{des.}) \right\} \left\{ \frac{1}{\text{rank}} \right\}^{0.025}$$

Our faculty members spend much time in conceptualizing these design projects. They need to be as open-ended as possible to encourage creative solutions and only include constraints that are

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necessary. They also need to allow a variety of approaches so that individuals with different interests can contribute to the solutions. One of the more difficult tasks is to propose projects that can be successfully completed in many different ways (i.e., that are multidisciplinary). If all the final student designs are similar, the project is generally discarded and not assigned again. Students need to be able to exercise their interests and creativity in successful problem solution and ALSO need to learn that usually there are numerous ways to accomplish most engineering tasks.

Lab activities

An important part of Engineering Problem Solving and Design is time spent in “laboratory” activities. These are not always laboratories in the classical sense of the word, but the term is used to embrace hands-on activities of many types. One of the most promising is discussed below.

Students often have a difficult time relating a physical process to its graphical depiction. This is easily seen by requiring students to construct a graph of a time-dependent process such as blowing up a balloon, a bungee jumper, or a person driving to and from work. Recently General Engineering was awarded an NSF grant to study the use of sensors in the classroom.⁴ These devices allow a real-time graph of a process to be obtained. These can be compared to graphs that the students are asked to construct before doing the activity. Literature described elsewhere indicates that this approach may be useful both to help students develop the ability to produce and interpret graphical representations of data, as well as help them understand the underlying phenomena. The incorporation of this into the curriculum has been greatly facilitated by the fact that all incoming engineering students must have a laptop computer; the sensors utilize the USB port and the software is available to all the students at no charge. For example:

Coffee cooling

Students are asked to sketch a graph that will show a temperature-time curve of cooling coffee. They can be asked to show additional curve for other conditions such as a lid on the cup, drinking it outside in the winter, a windy location, etc. The students then utilize the temperature sensor with their laptop computer to measure the cooling curve. The overall shape can be compared with their initial effort. Then as a second exercise, the students are asked to determine when cream should be added to bring it to a drinkable temperature most quickly.

Cantilever beams

Students are asked to answer questions regarding the amount of deflection expected of a cantilevered beam with such changes as: doubling the thickness, doubling the width, increasing the cantilever distance, etc. After completing this “quiz” the students use a force sensor (to measure the load) and a motion sensor (to measure the deflection) to study the beam. With this arrangement, they can generate force-deflection plots in real-time. This allows them to experiment with many configurations quickly and to draw conclusions about the relative importance of the various parameters.

We are in our first year of this project and so are just beginning to explore the various possibilities

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of these sensors. The many types available allow measurement of: force, linear motion, temperature, dissolved oxygen, pH, electric current, pressure, light, magnetic fields, rotational motion, and others. The overall procedure used is to expect the students to commit to a dependency before doing the actual activity. Once the activity is completed, the “real” results can be compared with their initial thoughts. These laboratory exercises not only improve the students’ abilities to translate phenomena to a plot, but they also teach a bit about how the world works.

Conclusions

The most effective and natural way to make the engineering curriculum multidisciplinary is through the incorporation of real-world activities. Ultimately, we seek to teach engineering from a multidisciplinary perspective because the practice of engineering is itself multidisciplinary. Since experiential learning has been shown by Kolb and others to be a useful component of the curriculum, engineering faculty need only focus on including real-world activities.^{5,6} This will facilitate the process of students discovering the multidisciplinary nature of engineering on their own, and the learning experience will be long-lasting.

Author biographies

BENJAMIN L. SILL

is Alumni Distinguished Professor of Civil Engineering and the Director of Clemson University’s General Engineering Program. He received his Ph.D. from Virginia Polytechnic University in Aerospace and Ocean Engineering in 1971. His research areas of interest are the effects of severe storms and environmental fluid flows.

MATTHEW W. OHLAND

is an Assistant Professor in Clemson University’s General Engineering program and is the President of Tau Beta Pi, the national engineering honor society. He received his Ph.D. in Civil Engineering with a minor in Education from the University of Florida in 1996. Previously, he served as Assistant Director of the NSF-sponsored SUCCEED Engineering Education Coalition. His research is primarily in freshman programs and educational assessment.

ELIZABETH A. STEPHAN

is an Instructor in Clemson University’s General Engineering program. She received her Ph.D. in Chemical Engineering the University of Akron in 1999. Previously, she has been an instructor and visiting researcher at the University of Akron and a manufacturing engineer at Dow Chemical.

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