“Engineering without labs [and design] is a different discipline. If we cut out labs [and design] we might as well rename our degrees Applied Mathematics” (Eastlake, 1986).

There is nothing wrong with a degree in applied mathematics, but that is not the degree that students and companies think they are getting. Design and laboratory classes are also important in accreditation (see Section 4.7), in the ASEE Quality in Engineering Education Project (ASEE, 1986), and in the Carnegie Foundation book on revitalizing engineering education (Sheppard et al., 2009). Despite almost general agreement on the importance of design and laboratory work, there has been a tendency in the past to cut these programs since they are expensive, messy, hard to teach, time-consuming, and not obviously connected to the university’s other mission—research.

We cannot delve into the technical details that become important in teaching design and laboratory courses, so the discussion will necessarily be more abstract. We will consider the purposes of design and laboratory work and then consider methods for teaching these courses.

9.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Discuss what design and laboratory work add to the education of engineers. Discuss the problems inherent in teaching design and laboratory courses.
- Develop a plan to incorporate design throughout the undergraduate engineering curriculum.
- Compare and contrast the different ways to teach design. Highlight the advantages and disadvantages of each method.
- Describe how you would select groups for a design project or laboratory experiment. Justify your method.
- Explain the appropriate laboratory structure for students at different levels.
9.2. DESIGN

There is good news about engineering design education. There is an increasing emphasis on design in engineering education (Dym et al., 2005; Froyd et al., 2013). Major design experiences (often called capstone design) have long been required by ABET. Capstone design courses were developed “in an effort to bring the practical side of engineering design back into the engineering curriculum” (Dutson et al., 1997). There is also a resurgence in first year or “cornerstone” engineering design courses (Dym et al., 2005; Froyd et al., 2013). First year design courses increase student development on the Perry scale (see Chapter 14) (Marra et al., 2000) and they increase retention of first year students (Knight et al., 2007). Although Rowan University has shown that engineering curricula can include design in all four years (Newell et al., 1999), at most schools, with the exception of computer engineering programs, the middle two years are barren of design. The Carnegie plan for reorganizing engineering education would include design in these years (Sheppard et al., 2009).

Many engineers contend that designing is the heart of engineering. All the mathematics, physics, chemistry, and engineering science courses are background for what makes engineering different from applied mathematics or the physical sciences. Yet, there is no universally accepted working definition of what design is. Prior to ECC-ABET-2000, ABET required one-half year of design in engineering curricula and listed the following activities and processes that might be included (ABET, 1989). Design:

- Produces a system, component, or process to meet a specific need.
- Is an iterative process that utilizes decision making with economics and employs mathematical, scientific, and engineering principles.
- Includes some of the following: setting objectives, analysis, synthesis, evaluation, construction, testing, and communication of results.
- Has student problems that are often open-ended, require use of design methodology and creative problem solving, require formulation of the problem statement and an economic comparison of alternate solutions, and may require detailed system details.

Programs would dutifully list the appropriate number of credits as design, but since many of the credits listed as design barely qualified, there was a continual struggle to be sure that sufficient design was included in the curriculum (Jones, 1991). An inadequate design curriculum was often noted as a deficiency during ABET visits.

Current ECC-ABET-2000 requirements for design (ABET 2013) are included in criteria 3c and 5. Criterion 3c lists the design outcome:

“an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”

Criterion 5 is concerned with curriculum. It states the curriculum will contain

“(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student’s field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the
one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.”

Criterion 5 continues with the statement,

“Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.”

We will first discuss appropriate goals for the design part of courses and then explore methods for teaching design and including design throughout the curriculum. Finally, we will examine four different methods for teaching design—design projects, case studies, guided design, and design clinics. What we will not attempt to do is to list activities or projects that are appropriate for teaching design in different areas of engineering.

9.2.1. Design Goals

Based on the ABET description of design a wide variety of possible goals for the design part of a course can be generated:

Problem definition and redefinition. Students will be able to define and redefine problem statements as they work their way iteratively through open-ended problems.

Synthesis and creativity. Students will be able to synthesize new designs using the principles of creative problem solving (see Section 5.7).

Troubleshooting. Students will be able to take an existing design that does not work up to specifications and make it work. Since troubleshooting is quite different than designing a new device or process, students need a chance to practice (Woods, 1980).

Use of engineering, mathematics, and science principles. Students will be able to integrate a variety of engineering, mathematics, and scientific principles into the solution of design problems.

Computer tools. Students will use computer tools such as spreadsheets, general mathematical packages, and engineering discipline-specific simulation packages to do detailed routine calculations. “A course which does not use professional software is preparing our students for a type of work which does not exist anymore” (Paris, 1991).

Decision making. Engineers must be willing to take the responsibility of making decisions knowing that something could go wrong since perfection can never be attained (Florman, 1987).

Economic evaluation. Students will evaluate solutions based on economic and other criteria to determine the best solution among several alternatives.

Completion of a deliverable. It may be possible to have students carry out all steps of a design including the construction and testing of a deliverable. When this is possible, it is extremely motivating for them to see their design built and used.

Industrial or real-life experience. Design projects are normally much more realistic than engineering science problems which are concocted to illustrate a single principle. An additional goal may be to have students solve actual industrial problems.
Oral and written communication. Students are expected to develop professional skills to communicate their results.

Planning and managerial skills. Students can learn how to plan effectively and direct fairly complicated projects.

Interpersonal skills. While working in groups students can learn interpersonal skills, become adept at teamwork, and start developing leadership skills. Teamwork has become increasingly important as technology becomes more complex (Florman, 1987).

Globalization. Engineering design has become globalized, and students in global teams produce better documentation of their projects (Dym et al., 2005) and are probably better prepared for industry.

Confidence. Students can develop confidence in their ability to function as engineers.

This is a long but certainly not all-inclusive list. Dekker (1989), Dym et al. (2005), Feisel and Rosa (2005), and Harrisberger (1986) discuss other possible goals. No single course can satisfy all these goals, although some professors make a valiant effort. However, an entire curriculum can be designed so that these and other objectives are satisfied. The professor’s task is to select appropriate goals for the design portion of a course. These goals must be appropriate for the student level and the time allotted to design. For example, completely open-ended, unstructured problems with no guidance are not suitable for first-year students but may be very appropriate for seniors. Once the goals have been determined, teaching methods can be selected (see Sections 9.2.2 through 9.2.7).

9.2.2. Teaching Design

The old ABET literature (e.g., ABET, 1989) explicitly states that material in engineering courses can be split between engineering design and engineering science. A strict dichotomy between engineering science and engineering design is a false one. The engineering design experience should be developed and integrated throughout the curriculum. Sheppard et al. (2009) propose using design and laboratory throughout the curriculum as a means of teaching students the professional aspects of engineering. The new ABET requirements (ABET 2013 and Section 4.7) require a meaningful, major engineering design experience.

Spreading design throughout the curriculum allows the faculty to develop a design experience where students start working open-ended problems as freshmen or sophomores. These first projects are presented with a significant amount of guidance using a procedure such as guided design (see Section 9.2.5). Procedures for teaching freshmen design are discussed by Marra et al. (2000), and Dym et al. (2005). The best methods such as the Integrated Teaching and Learning Program and Laboratory (ITL) at the University of Colorado-Boulder use hands-on projects (Knight et al., 2007). The prime movers in creating the ITL and courses it supports, Jacquelyn F. Sullivan and Lawrence E. Carlson, were recognized for their contributions to engineering education with the 2008 NAE Bernard M. Gordon Prize.

Ideally, design ideas would be included in traditionally non-design classes in both the second and third years, or design studios can be continued during these years (Newell et al., 1999). Unfortunately, the sophomore and junior years are often devoid of design. The Carnegie Foundation study recommended greatly increasing the amount of design in these two years (Sheppard et al., 2009). The first year design courses and the traditional senior
design classes and design laboratories would be retained. However, students would be better prepared for senior design, and professors would see fewer students who are totally unprepared for open-ended design problems.

Introducing some ideas of engineering economics into the curriculum during the first or second year allows a professor to include relatively simple design problems and economic optimizations that can only be talked about instead of being done if the students have not studied economics (Sullivan and Thuesen, 1991). Talking about something is a totally ineffective teaching method; students must do what they are to learn (Sheppard et al., 2009, Chapter 21). In our experience, students find some of the economics (costs, cost indices, payout periods) easy, while other parts (such as discounted cash flow) are more challenging. It helps if the textbook talks about economic factors, but unfortunately many engineering textbooks are written in an economic vacuum. Since students see the design problems with economics as real engineering, these problems are motivating as long as the professor does not overburden the problem with detailed calculations. Computer tools such as spreadsheets, mathematical packages, and simulation programs are appropriate here to remove the burden of routine calculations.

How do you add design focused problems to an already overloaded curriculum and overloaded courses? In some courses substitution of open ended design problems for some of the single answer problems used currently will be straightforward. In other courses it will be necessary to reduce the coverage in lectures and expect students to learn some of the material on their own. If the design problem includes this material, students will learn it, and they will learn how to learn on their own. You can help by having clear objectives, making sure resource material is readily available, and believing that students can master the material on their own. The design problem can be included as a small project, a case study, or as a guided design project.

Another aspect of design is the use of off-the-shelf components. Standard components can easily be introduced into straight-forward design problems in sophomore and junior courses. For example, in a course on fluids or hydraulics students can be required to learn on their own about components such as valves, pumps, pipe joints, and pipe supports. The Visual Encyclopedia of Chemical Engineering Equipment (Montgomery, n.d.) is a good source for equipment of interest to all engineering disciplines.

An important part of design is creativity and synthesis. Since most traditional curricula cover only application and analysis during the first three years, it should be no surprise that many students have difficulty with creativity and synthesis in senior design. Including creative exercises and synthesis problems throughout the undergraduate program should make most students more creative designers. The methods for teaching problem solving and for fostering creativity discussed in Chapter 5 are appropriate for the design component of classes if they are integrated with the class content.

There are many significant difficulties in teaching design at any level. The first difficulty is the development of good design projects. Every engineering professor has one or two good design projects stored in her or his head. Design projects can be recycled and reused by giving the students electronic files of all the reports and telling the students to improve on the designs. However, this cannot be repeated too many times. New projects are needed probably every two or three years. Thus, the first cycle is not the problem; it is the second, third, and following cycles. There are sources of problems that can be tapped by professors but
are unlikely to be tapped by students. Published case studies (see Section 9.2.5) and professional society design contest problems such as the American Institute of Chemical Engineers Contest Problem are useful. Industrial interaction can produce interesting problems with the added benefit that the problems are “real” (Emanuel and Worthington, 1987). Ring (1982) suggests that cities can be used as a source of problems. Other rich sources of projects are designs for people with disabilities (Hudson and Hudson, 1991), local non-profit organizations, non-governmental organizations (NGOs), and hands-on museums. Finally, we suggest that professors from different institutions collaborate on developing design problems. Each year a professor from a different school could develop a problem and all the schools would use the problem and grade their own students. The labor of preparing new problems could thus be reduced significantly. In addition, student teams constituted from a number of schools would help prepare students for the globally networked teams common in industry.

9.2.3. Team Selection and Grading

Since design problems are usually team efforts in industry, it is appropriate that they be team efforts in school. Some professors allow students to pick their own teams. This does not follow industrial practice and tends to result in teams that are very uneven in ability. Emanuel and Worthington (1987) suggest that professors assign groups with the following selection criteria:

- Mix leaders and followers within a team.
- Distribute abilities and experience among teams.
- Place one person with initiative on each team.
- Mix foreign students among teams to force communication in English.
- Do not put roommates on the same team.
- Mix men and women in teams; however, in lower level courses women and under-represented minorities should be put in teams in pairs.
- Use teams with three members.
- Be sure at least one team member lives close to the campus as this facilitates copying, computer use, and so forth.
- If travel to a company is required, be sure at least one student in each group has a car.

We would add to this list:

- Mix students with industrial experience such as co-op or internships among teams.
- Mix students with computer skills among teams.

The MBTI (see Chapter 13) has been used for team selection (Emanuel and Worthington, 1989). However, dysfunctional teams can result if team members try to act in accordance with their Myer-Briggs type instead of as is appropriate for the situation (Emanuel and Worthington, 1989). After trying different selection procedures, Emanuel and Worthington (1989) stopped using the MBTI for selection but instead used it to help the groups function better during the semester.

Groups malfunction for a variety of reasons. Perhaps the most common problem arises when one student does not do a fair share of the work. If the class is to be a learning experience in teamwork, you should not ignore these problems. The MBTI can be used as a diagnostic tool to help explain the problems; however, do not allow students to use their type as an excuse. Instead, tell students that the types show weaknesses that they must work on. Even without the MBTI you should encourage students to discuss group problems and then meet with the group to try
to find resolutions. Design groups can be considered as a type of cooperative group, and many of
the comments in Section 7.4.2 are appropriate for instruction and management of these groups.

Grading of groups can also be a problem. Since the group is producing a group report,
it is appropriate to give the students a group grade. However, students often feel that this is
unfair if one student has not done a fair share of the work. This problem can be resolved in
several ways. Talk to individual students and then to the group, and if appropriate assign a
lower grade to the shirking student. Second, give the students a group grade and have the
group assign points to each student. Most groups will assign each student an equal number
of points, but groups where one student has obviously shirked responsibility will differentiate.
However, Eck and Wilhelm (1979) point out that these groups often engage in significant
conflict over grade distribution and that some type of arbitration scheme may be necessary.
Third, require every student to turn in an individual progress report every week (Stern, 1989).
From these you can usually make a rational decision on how to partition the final grade (and
incidentally can usually predict which groups will turn in good reports). Fourth, assign all stu-
dents the same grade despite the claims of unfairness. Fifth, design a formula for partitioning
the grade so that a variety of inputs are included. (Emanuel and Worthington, 1989). Finally,
use the online tool CATME (CATME, 2013; Ohland et al., 2006) or other peer evaluation
scheme to obtain rich feedback from all the group members.

What about important technical content that was either skipped in prerequisite classes
or which students did not learn? A significant portion of many design courses cover econom-
ics, but this time should not also be used as a catch-all to reteach other material. Provide the
students with resources (perhaps their own textbooks) and have them learn or relearn the
material on their own. Engineering students can be surprisingly efficient learners when they
see the need to learn material in order to complete a design assignment.

A final significant problem in design classes is time—both student and instructor time.
Students need to learn how to develop a work plan and how to schedule a design project. In
addition, some help in improving efficiency is appropriate. If design is included throughout
the curriculum, then efficiency, time management, and scheduling can be discussed every
semester. This repetition is helpful in learning how to apply these ideas. The problem with
instructor time is that many universities undervalue design classes and overload professors
who are teaching these classes. Design classes are time-consuming because of the need to
develop problems, consult with student teams, and grade lengthy reports. Providing suffi-
cient resources for design requires an administrative solution, which should include sufficient
rewards for professors teaching these courses (Jones, 1991).

9.2.4. Design Projects

The most common way to teach design is with project-based learning (Dym et al., 2005; Du
et al., 2009). Students, usually in groups, are given a design problem and told to do the design.
Since engineers learn design by designing, this is certainly an appropriate procedure. In addi-
tion, people remember the things that they do. We can remember our senior design (and
laboratory) projects after forty-five years, but we don’t remember details of any of the lect-
ures. The projects must be open-ended to be considered design. Multiple solutions of a well-
deﬁned problem are optimization, not design (Dekker, 1989). The emphasis of project-based
learning is on applying and integrating knowledge and skills while problem-based learning
(Section 7.5) focuses on learning new knowledge and skills.

The amount of guidance students need depends upon their maturity. Freshmen need
significant guidance, and a guided design procedure (see Section 9.2.6) should be consid-
ered. Seniors need the opportunity to solve significant design problems with little guidance.
It is helpful if students have the opportunity to work up to a totally unguided design project
by working on increasingly difficult designs with decreasing guidance during their junior
year and first semester of senior year. Design projects can be classified in many ways. Dekker
(1989) suggests classifying them on the basis of various dichotomies.

- Fun versus serious
- Academic versus real world
- Paper versus hardware
- Creative versus structured
- Individual versus group
- Disciplinary versus interdisciplinary
- Small versus large

Fun projects can include brainstorming a float design for a parade, creating a “Rube
Goldberg” design, and so forth. Hardware projects, which mix design and laboratory skills,
can be extremely motivating, because students can see what they have designed. Dekker
(1989) suggests that designing will be creative if students design something that is unknown.
For example, have them design a “dollar bill picker-upper” or a unique machine that will
only be used to make advertisements interesting to sell a common household item. Creative
designs can be encouraged by showing students one design for accomplishing a task and then
asking them to develop a competing design. This can be made more realistic by giving them
the patent and telling them to develop a design that does not infringe on the patent. This pro-
cedure also brings up the subject of patents and patent law in a meaningful way.

Since many companies use interdisciplinary design teams, an interdisciplinary project is
a useful experience, and ABET requires the ability to work in multidisciplinary teams. With
advances in globalization international teams are also of interest and would certainly help stu-
dents satisfy ABET criterion 3h. The technical performance of global teams competing in the
Lincoln Arc Welding Design Competition was equivalent to US teams, and their documenta-
tion was better (Dym et al., 2005). A series of small projects allows for variety, different lead-
ers, multiple grading opportunities, and a gradation in the degree of guidance. Large projects
allow for more realistic problems, can be more open-ended, and require much more detailed
planning and scheduling. It is useful if students see some of each of these different types of
projects during their period in school.

It is obviously desirable to use projects that are real and have input from practicing engi-
neers from industry or government. A variety of ways of obtaining this input are discussed by
Harrisberger (1986), among others. Setting up the appropriate industrial or government con-
tacts can be very time-consuming. Once the contacts have been made, you need to arrange for
sponsors. Companies are much more serious about design projects if they pay for the direct
costs (not including labor) of the projects. Requiring payment helps to ensure their continued
interest. Projects must be screened since some may be too easy or too difficult for the time allot-
ted. A company engineer needs to be involved in the evaluation of projects, but if many different
companies are sponsoring projects, you need to control grades to ensure uniformity in grading. Other additional problems include the need for student travel to and from the client and the occasional lack of cooperation when a company refuses to release necessary information.

Balancing the difficulties in working with companies on design projects are the benefits. The opportunity to work with practicing engineers can give students contacts for future jobs and references. There is no question in their minds that the project is real and relevant. Students are often surprised by the messiness of real problems and the difficulty of relating them to the mathematically tractable problems solved in class. Professionalism is obviously important, and students are more likely to behave as professionals. Finally, successful performance can give students the confidence that they can be successful engineers and can on occasion result in a job offer.

A different type of hands-on design project is reverse engineering and redesign (Ingle, 1994; Wood et al., 2001). Students take apart an object such as a toaster or a bicycle to determine how and, if possible, why it was designed in a particular way. Students are required to keep careful records of each disassembly step. To ensure that the students are careful and record not only where all parts go but also their configuration, they should be required to reassemble and test the device when finished. The student groups are then asked to redesign the object to improve it in some way. Since redesign should also include design that does not infringe on any patents, this step is a natural point to bring in a discussion of the US patent system (Garris, 2001). In engineering disciplines such as chemical engineering, industrial engineering, and nuclear engineering where processes are designed, reverse engineering can be done by dissecting a detailed flow sheet piece-by-piece.

Regardless of the type of project, both oral and written reports should be required to stress communication. Weekly progress reports are useful to help prevent procrastination and to pinpoint problem groups. If a company is sponsoring the project, a presentation to the company is in order, but only after a full-scale dress rehearsal in front of the faculty.

### 9.2.5. Case Studies

A case study is a detailed description of how a professional approaches a problem. A number of engineering case studies are listed as available on the web for purchase or subscription (do a Google search). The American Society of Civil Engineers (ASCE) is particularly active in the development of case studies. In addition, many descriptions of solving tough engineering problems are available in books (e.g., Bosela et al., 2013; Herring, 1989) and in the trade literature. Patents can also serve as case studies (Garris, 2001). Videos are available for a number of chemical industry accidents [http://www.csb.gov/videos/](http://www.csb.gov/videos/), and case studies could be built around these videos. Section 4.8 presents a case study in curriculum development.

The best cases contain most of the following (Weaver et al., 1994):

1. Use “real” cases based on real data. They have the advantage that the resolution can be explained after the case is finished. Weaver et al. (1994) think fictional cases are OK, but Naumes and Naumes (2000) strongly disagree.
2. Include disinformation (extraneous data) because in real design disinformation is always present.
3. Provide sufficient description of the situation including the characters and dialogue so that students can interpret what the characters are thinking in a variety of ways.
4. Write reasonably complex cases.
5. Include a core of information which can be related to theory, research and knowledge.
6. Develop a primary theme and ancillary issues. Deliberately entangled primary and important tangential issues are realistic.
7. Make the case provocative and important to the students.
8. The presentation should not provide a resolution to the problem.

Case studies can be used in a variety of ways and are useful in both design and non-design classes. Herreid et al. (2012) classify the use of case studies as (a) individual assignments, (b) lecture format, (c) discussion format, and (d) small group format. They argue that the discussion and small group formats are most useful in engaging students. The “Interrupted Case Method” is recommended because it approximates the way much engineering work is accomplished. The students are first given background information and then the case is interrupted while the students study the problem. Next they are given more information and asked to do more work. After the students have finished, the actual final results are presented.

Case studies, particularly of failures, are excellent for satisfaction of the ABET professional outcomes (Delatte et al., 2013). Many case studies consider ethical questions and provide a basis for discussion. They also help to introduce the engineering profession and motivate some students. Case studies are useful in introductory engineering classes to help show students that the material being studied is relevant. Yadav et al. (2010) compared student test scores in a mechanical engineering introduction-to-modeling course for students in a section taught by the case study method to students in a lecture section. The method of instruction produced no significant difference in the students’ test scores; however, students in the case study section thought that this form of instruction was beneficial in learning the material and that they were more engaged than in lecture courses.

Case studies can be used in design classes, although they are not a substitute for project work since they are less open-ended (students will consider the case study the solution). Instead, case studies should complement projects. They are particularly useful in showing the human aspect of engineering. And they can show the importance of non-technological factors, such as marketing, in the success of products. Instructors can also obtain project ideas, data, a scenario, and so forth, from a case study.

Case studies are extensively used in law and business schools. Myers (1991) discusses the history of case studies and provides references for applications outside engineering. He notes that Harvard Business School introduced a seminar for professors to teach them to teach with case studies. Naumes and Naumes (2000), writing from a business background, discuss the exhaustive process of developing, writing, and testing a case study.

Instead of writing a case study and giving it to students, professors can have student teams develop case studies as a course project. The teams would need to be given examples of good case studies to use as models.

9.2.6. Guided Design

Guided design is a structured way of having students work through case studies step by step and provide feedback after each step. This procedure is particularly appropriate for introducing students to open-ended design problems since there is considerable guidance and feed-
back throughout. Guided design was developed by Charles Wales and his coworkers (e.g., Heywood, 2005; Stager and Wales, 1972; Wales et al., 1974a, 1974b; Wales and Nardi, 1982). Guided design was first developed for engineering classes and has since spread to a variety of other disciplines.

The guided design procedure is well summarized by Wales and Nardi (1982). The professor uses printed handouts to guide teams of five to six students through an open-ended problem in “slow motion.” After the groups are formed, the guided design procedure starts with a printed handout which explains the problem situation and the student roles. The student groups then define the problem statement and set goals. This is done by a cooperative group discussion (see Section 7.3). After five to twenty minutes the groups receive a printed sheet which tells what the professional engineer did. It is important to stress that this feedback sheet does not represent the solution but shows what one professional did. This point can be made quite clearly if some of the feedback sheets contain actions which are not particularly clever or are ethically dubious. The student groups then discuss the printed feedback sheet and compare their responses to that of the professional engineer. Since it is the design process which is being taught and not a particular answer, the professor must be careful in evaluation.

The guided design procedure then advances step by step through a specific problem-solving or design procedure. For example, the problem-solving strategy in Section 5.4 can be used. Wales and Nardi (1982) recommend the following ten steps:

1. Outline situation
2. Define goals
3. Gather information
4. Suggest possible solutions
5. Establish constraints
6. Choose solution path
7. Analyze factors needed for solution
8. Synthesize solution
9. Evaluate solution
10. Make recommendations

When we used guided design, we made step 5 the third step in the process.
For each step the students first complete the step and then receive and discuss the feedback.
Guided design projects can take from two hours to several weeks. At the end of the guided design students can be required to communicate their results orally and in writing. While the guided design proceeds in class, the students can be assigned readings and homework for outside class. The groups can be encouraged to meet outside class as cooperative learning groups.

Although guided design was first developed as a procedure where all information transfer was in printed form (books and handouts), it can easily be adapted to the laboratory portion of a lecture class (Eck and Wilhelm, 1979). For students who are unfamiliar with working in cooperative groups, it is useful to use the first laboratory period for exercises in interpersonal communication, such as paraphrasing, self-disclosure, maintenance contributions to the group, and an ethics exercise with student observation (Eck and Wilhelm, 1979). After every group exercise, do some group processing to help students improve their skills.

What do you do in guided design? You must prepare or select the case studies and put them into a guided design format. Some prepared projects are available (Wales et al., 1974;
Eck and Wilhelm, 1979). If a prepared guided design project is not available, then you can convert old design projects, convert case studies, or develop new projects in the guided design format. Potential developers need to be aware that developing a good guided design project from scratch is very time-consuming.

Wales and Nardi (1982) discuss the development of new guided design projects. First the project must be outlined and divided into labeled steps following the problem-solving or design strategy of choice. A story line and realistic roles must be developed for the students. This step is important since it establishes a need for the project and helps to motivate the students, who must be active in each step. Since learning the process is the important goal, students should gather information only once and have an opportunity to practice the decision-making steps. Students should be asked to make important decisions. Asking them to make trivial decisions reduces the credibility of the entire project.

The form of the written feedback is important, as it models what an experienced engineer does to solve the problem. Be sure to write that the engineer would have done the following, not that you should have done the following. Since the problems are open-ended, the feedback can serve only as a model of possible actions. The students may tend to resist this at first, so be careful not to reinforce their belief that this is the correct solution. Be sure that the feedback responds to the questions that the students were asked in the instruction.

In a guided design class students must learn the content outside class by reading, discussing in their groups, doing homework, and so forth. In class they learn how to apply this content to open-ended design problems. You need to be sure that the printed learning materials are good. If the textbook is not clear, then additional notes or study guides must be developed. Some class time needs to be available for answering questions, reviewing the homework, making class assignments and so forth.

Once the guided design period starts, you are a guide and coach, not a lecturer. The first challenge is to form groups and to get the groups off to a good start. Group assignments are discussed in Sections 7.4 and 9.2.3. During the project you and the TA can circulate among the groups. If a group is functioning well, just listen and then briefly provide some positive feedback such as, “This is a great discussion. Keep it up.” Some groups will need help getting started. Ask questions about the project or about group processing. If necessary, appoint a leader and a recorder. The behavior of students is often markedly more focused if they have an assigned role. To provide proper feedback to the groups, you or a TA should be available for every twenty-five to thirty students.

There are a variety of ways to assign group project grades. One approach is to have the groups assign the grade that they think they have earned. If their grade is higher than what you think they have earned, make them redo their project and their report until they have earned the higher grade (Eck and Wilhelm, 1979). This procedure is most appropriate for long projects.

The results reported for guided design have been impressive (Eck and Wilhelm, 1979; Heywood, 2005; Stager and Wales, 1972; Wales and Nardi, 1982). The instructor spends much more time with the students on high-level cognitive tasks. And they show better retention, higher grades both in the guided design course and in follow-up courses, increased confidence, and greater motivation. The classes show more cooperation and better group dynamics than other design classes. Students rate guided design classes higher than they do other
design classes. However, it is not uncommon to have one or two poor groups that do not function well. The members of these groups do not fully benefit from the course.

As noted previously (Sections 7.2 and 7.7.2), engineering education has cycles and fads. Guided design was a minor fad while Charlie Wales, the charismatic developer of the method, disseminated the method at numerous meetings and presentations. The fad has died out and a useful teaching method is currently seldom used.

9.2.7. Design Clinics

Actual practice in engineering is obviously beneficial to students. A design clinic is one way of providing an internship activity. Other approaches to providing industrial experience are industrial cooperative programs and summer internships. The following are advantages of the design clinic approach (Harrisberger, 1986):

- Students have a significant industrial experience.
- Students make contacts with practicing engineers.
- Students become confident and more professional.
- The design clinic can fit into the normal course structure.
- Students need no extra time for graduation.
- The design clinic can be controlled by faculty members.
- The design clinic can be self-supporting.

There are models of the design clinic approach at Harvey Mudd College (Bright and Phillips, 1999), University of Alabama (Harrisberger, 1986), Rowan University (Newell et al., 1999) and the University of Michigan (Michigan Engineering, 2014). Clive L. Dym, M. Mack Gilkeson and J. Richard Phillips, were recognized with the 2012 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education for their development of the Harvey Mudd Design Clinic.

The design clinic assumes that basic technical knowledge has been covered in other courses. In the clinic, students first learn a variety of skills and then apply them in a supervised professional practice working on a real industrial problem. For example, students take a three-credit skills course in the first semester of their senior year, which consists of two seminars and one three-hour lab every week. In the seminars the students have lectures, take diagnostic tests such as the Myers-Briggs Type Indicator, make and critique presentations, listen to panels, and so forth. The content is concerned with the practical aspects of engineering instead of technical content. Thus students learn skills for presentation, listening, writing, record keeping, teamwork, leadership, project planning, creative problem solving, design methodology, retrieving and finding information, persuasion, and assertiveness.

The laboratory portion of the skills course consists of group projects in which students have the opportunity to practice the skills covered in the seminars. The laboratory is also used to introduce them to the solution of open-ended design problems. The projects done in the laboratory consist of an ideation exercise, a management simulation game, an extensive guided design project, and an extensive competitive design study. Note that the class starts with significant guidance in solving open-ended problems and then reduces the amount of structure.

During the second semester students take an internship course. Groups of three work on company-sponsored problems. The companies are expected to pay all direct costs, often on
the order of $10,000 per project which includes a clinic fee to cover administrative expenses. The design group visits the company for an initial visit to learn about the problem and for a final written and oral presentation. Other visits may be scheduled if needed. All companies are within a four-hour drive of the campus, and student groups are selected so that at least one member has a car. The companies are expected to provide the necessary information and to have an engineer work with the students as needed.

Every group meets with a faculty coach once a week for twenty to thirty minutes. This coaching helps keep the students from procrastinating and keeps them focused on solving the problem on time. Each group presents a midterm progress report in the clinic. A dress rehearsal is presented in front of a faculty jury before the final presentation to the company. All professors in the department are modestly involved by coaching two design teams, which takes about one hour per week. Administrative details of running a clinic are discussed by Harrisberger (1986).

Although the design clinic idea has not been widely adopted, it does appear to be a cost-effective way of providing an industrial internship for all engineering students. In addition, design clinics do not require that the faculty have extensive industrial design experience to teach design.

9.2.8. Design Competitions

Many competitions, such as robot competitions (Firebaugh, 2008; Hernando, 2011; Miksell et al., 2012), the solar house, solar powered car, unmanned vehicle competitions (Paulik and Krishnan, 2001), Baja SAE, and human powered vehicle challenge (Miksell et al., 2012), are inherently multidisciplinary, fit well into design courses, and are strong motivators of many students (Grose, 2011; Wankat, 2005). Since ABET criterion 3d requires multidisciplinary teamwork, design competitions are a natural fit. Competitions that are not multidisciplinary such as the ASCE concrete canoe competition or programming competitions also make excellent design projects, but criterion 3d needs to be assessed in other courses.

One reason competitions increase student learning is that many students buy into the competition and spend a significant amount of time working on the project. It is not clear if the amount of learning per time spent is higher or lower than in standard classes; however, many of the skills learned are different. In a design and build competition the students gain hands-on, practical experience they often do not obtain anywhere else. Long-term competitions often enhance the confidence of students as they realize they can build something that works as designed (Wankat, 2005).

Competitions are a rich environment for assessing satisfaction of ABET criteria for student outcomes. In addition to ABET design criterion 3c, competitions usually include an experimental component (3b), a knowledge (3a) and problem solving component (3e), and very often use computer design methods (3k). On the professional side in addition to criterion 3d, students invariably must communicate their results (3g). Many competitions will involve the student in the economic or societal context (e.g., solar house) or will involve a design for a developing country—both of which are part of criterion 3h and often include contemporary issues such as energy (3j). The professor in charge of the project could easily bring in criterion 3f—professional and ethical responsibility. That leaves only criterion 3i, life-long learning, that does not occur almost automatically as part of the competition.
What factors lead to the same school winning a contest repeatedly? After studying this question, Wankat (2005) determined that the following factors were important:

1. A dedicated faculty adviser.
2. Close alignment between the curriculum and the contest.
3. Tangible university support including equipment and space.
4. A tradition of winning.
5. Strongly motivated students.

9.3. LABORATORY COURSES

More than any other topic in this book, teaching laboratory courses in engineering is specific to the field of engineering and the type of laboratory. Since we must avoid discipline specificity, this section is an abstract discussion of the most concrete part of engineering education—the laboratory.

In contrast to the fairly extensive discussion of design ABET has little to say about laboratory (ABET, 2013). Outcome 3b is “an ability to design and conduct experiments, as well as to analyze and interpret data.”

Criterion 7 on facilities lumps laboratory facilities with other facilities:

“Classrooms, offices, laboratories, and associated equipment must be adequate to support attainment of the student outcomes and to provide an atmosphere conducive to learning. Modern tools, equipment, computing resources, and laboratories appropriate to the program must be available, accessible, and systematically maintained and upgraded to enable students to attain the student outcomes and to support program needs. Students must be provided appropriate guidance regarding the use of the tools, equipment, computing resources, and laboratories available to the program.”

Laboratory has become the underdeveloped stepchild of engineering education. ABET has not paid much attention to labs, schools tend to minimize lab work because labs are expensive and consume space, faculty often avoid teaching lab courses because they are time consuming and the teachers are not rewarded for their efforts with high student evaluations, and most students prefer other courses.

9.3.1. Purposes of Laboratory Courses

Laboratory courses can have a variety of different purposes, many of which are explored by ASEE (1986), Eastlake (1986), Fiesel and Rosa (2005), and Sheppard et al. (2009). Since the laboratory and the course structure depend upon the purposes of the laboratory course, these objectives should be decided upon first. No laboratory can be optimal for all purposes. The goals for the course can include:

Experimental skills. Students can learn a variety of skills involved in doing experimental engineering work. These can include certain psychomotor skills, planning an experiment, recording, analyzing and interpreting data, and using modern measuring instruments.
Real world. Students can learn to function in a real-world environment where the theory may or may not work and the equipment occasionally malfunctions. They can learn to distinguish reality from theory. They can also experience working in a climate of uncertainty and can learn the manifold meanings of Murphy’s law. In other words, laboratory serves “to bring the ‘real world’ into an otherwise theoretical education” (Feisel and Rosa, 2005, p. 123).

Build objects. Students can actually build and test their designs. A sense of craftsmanship can be gained. They can learn to use working models to solve engineering problems (Hills, 1984). Models are used in many industrial settings but are often ignored in the education of engineers.

Safety. Safety is a real world issue often ignored in theoretical courses. Safety should always be considered in designing experiments and safety rules should be rigorously enforced in the laboratory.

Discovery. Students can discover results which can improve theory and reinforce their ability to predict the results of using complex devices.

Equipment. Students can work with modern equipment, which adds a concrete aspect to an otherwise abstract education. While working with equipment, students can also learn about the importance of safety.

Motivation. “The theoretical work was difficult—some of it exceedingly so—but the physical doing made it seem worthwhile” (Florman, 1987, p. 8).

Teamwork. Many laboratories are team efforts, and students can learn to function as part of a team. This can include an opportunity to be the team leader.

Networking. Students may have to find information from a variety of sources including industrial contacts, professors not connected with the laboratory, technicians, and so forth. This is an appropriate experience before accepting their first industrial position.

Communication. Both written and oral communication skills can be emphasized through preparation, progress, and final reports.

Independent learning. Since all the knowledge needed for laboratory classes will not be at their fingertips, students will have to independently review old material and learn new material. This can help prepare them for the real world where independent learning is important.

We have not tried to be encyclopedic, and there are obviously other purposes for laboratory courses (e.g., Feisel and Rosa, 2005; Heywood, 2005; Sheppard et al., 2009).

9.3.2. Laboratory Structure

The structure of the laboratory should depend upon the major purposes of the course. It can range along a continuum from a totally structured, cookbook-type approach to a partially guided experience to an unstructured class. A cookbook approach can be satisfactory if the purpose is to develop psychomotor skills and the ability to use measuring instruments. These purposes have become less important as easy-to-use digital instruments have replaced analog instruments which often required considerable expertise. However, learning to use instruments or tools is still a legitimate purpose for a laboratory course. A cookbook approach may be used when the purpose is to reinforce theory, but a discovery approach is more effective.

In an unstructured laboratory students are given fairly general instructions or goals. The goal may be to design and build a new logic circuit, to survey a new subdivision, or to scale up a chemical process. The students must decide what needs to be done and how best to do it.
An unstructured laboratory might ask students to explore a phenomenon such as the effect of pH and temperature on a biochemical reaction. No other directions are given. Unstructured laboratories are certainly appropriate for seniors who are mature enough to handle the uncertainty and who need the experience in planning and decision making before graduation.

Lower-division students may be lost in an unstructured laboratory. A partially guided experience is appropriate. A student is given some guidance in setting up the experiment and told what to do first. For later parts of the experiment much of the detail is left to the student. For example, a student can be told to look at the effect of several temperatures in a given range but not be told how many or which temperatures to use. In addition, the student would not be told what to expect although he or she might be told to predict the behavior.

Laboratory experiments appear to be most effective when the solution is not known ahead of time (Heywood, 2005). Measuring an orifice coefficient when fifty other students have already done so is not the stuff of a marker event. As a professor you need to be creative. Assume, for example, that the method of measuring an orifice coefficient is important in a fluids laboratory. The method will be learned much better if the student is given a noncircular hole as the orifice. Where does one look up the orifice coefficient for ellipses, rectangles, parallelepipeds, and triangles? What about five- or six-pointed stars and quarter moons? By varying the dimensions and the shapes, each student group can do a unique experiment, and the groups will not be able to dry-lab the results. In addition, this sort of “research” can eventually result in a technical note. Being the coauthor of a technical note or presentation (even if it is in a student magazine or at a student convention) will make the laboratory a marker event for the students. If time is available, this type of laboratory experiment can be made even more useful by asking students to predict the behavior of their orifice ahead of time.

Laboratory classes can be structured to reinforce lectures not with cookbook exercises but with the scientific learning cycle or with Kolb’s cycle (see Section 15.2 or 15.4, respectively). Do the laboratory work before the topic is covered in lecture and have the students explore the phenomenon. Let them discover many of the characteristics of the device. For instance, in the orifice example the students can determine the general form of the equation relating velocity to pressure drop. Then in lecture the theoretical development will be much more believable and would already have been partially verified. The students will be more likely to appreciate the power of theory to include additional terms without needing additional experimentation. The lecture would be the term introduction step in Figure 15-1. For concept application students can use their data to determine the orifice coefficient and solve additional problems.

Process-oriented design laboratories (e.g., chemical, industrial and nuclear engineering) typically ask students to design a large-scale apparatus or process. The purpose of the laboratory is to determine coefficients or efficiencies needed for the design. Students must determine what must be measured and must allocate their time between laboratory experimentation and design calculations. Unfortunately, a substantial minority of students have difficulty determining what key experiments will be useful (Heywood, 2005). Product-oriented design laboratories (e.g., civil, electrical, and mechanical engineering) often have design, build, and test projects. Balmer (1988) believes students should solve real industrial problems and test their solutions in the laboratory. An alternative is to have the students design a product that does not exist and test it in the lab.
9.3.3. Nitty-Gritty Details

A number of decisions must be made in any laboratory course. Should the laboratory be part of a lecture course or should it standalone? If the purpose of the laboratory is to reinforce the theory and allow students to discover results, then a laboratory attached to a theoretical course makes sense. Scheduling is easier, and the connection between experiments and theory will be more obvious. If the purpose is to synthesize several theory courses and have students design or build something, then a stand-alone course with appropriate prerequisites makes sense. In either case, the laboratory workload should be congruent with the credit granted. If students are supposed to be able to finish laboratory experiments and reports in the laboratory, then it needs to be structured so that at least the better groups can do this.

Should students work individually or in teams? Although there are a number of reasons why teamwork is beneficial to students, the decision is often made on the basis of availability of apparatus. Equipment availability often determines team size, but most schools seem to have settled on two students for bench scale equipment, and three or four students per group for larger equipment. If teams are used, how should they be selected? It is better to make a rational choice than just to continue what has been done for many years (see Section 9.2.2).

Require students to plan their experiments in advance. Many laboratory courses require students to pass an oral readiness quiz before they can go into the laboratory. This is a good safety precaution which encourages students to think before experimenting. In a design laboratory with projects lasting four weeks, we found it useful not to allow students to collect any experimental data during the first class. This time was spent in planning.

What types of records should students keep, and how should they report their results? Laboratory notebooks are commonly used in industry to support possible future patent claims. Engineering laboratory is the best place to practice keeping a neat laboratory notebook that follows industrial practice (McCormack et al., 1990). Since communication is often an important goal of the laboratory (and all too often of only the laboratory), both oral and written reports are often required. The best feedback for oral reports can be provided by recording student presentations on video and having them watch themselves—event writing a brief “review” of their performance (see Section 8.2.5). For written reports the most improvement in writing will occur if students receive prompt feedback and then rewrite the report for a grade. This obviously requires proper scheduling of the laboratory session and diligence on the part of the instructor.

The quality of the equipment in the laboratory is a never-ending problem, and obsolete equipment and poor maintenance can cause difficulties when programs are accredited. We do not see any substitute for modern instrumentation. Components such as resistors and transistors and major pieces of equipment such as nuclear reactors, distillation columns, or jigs do not have to be new, but the analytical instrumentation does. For example, retire mechanical balances. If the purpose is discovery, much of the equipment can be simple and homemade. If the purpose is to familiarize the student with industrial equipment, use commercial equipment. There is no substitute for a planned and funded maintenance and equipment replacement program. Safety should be a primary concern when equipment is repaired and when new equipment is purchased. Safety needs to be stressed with undergraduates (and with TAs). Stern measures are taken in industry when workers fail to follow safety rules, and stern measures should be taken with students who do not follow safety rules.
Teaching assistants may try to avoid laboratory assignments because they are often more work than grading papers in other courses. The department needs to be sure that the workloads for all TA assignments are appropriate and roughly equal. Laboratory TAs usually have significant contact with the students; thus, they should be able to communicate well. TAs often need to be trained, and a convenient time to do this is the week before classes start.

Laboratory courses need to foster both interdependence and individual responsibility (see Section 7.4.2). Each student's grade should be partly based on team results and partly on the individual effort. Encourage groups to make the laboratory a group effort, not merely a leader with two drudges. Professors and TAs should regularly circulate through the laboratory and observe groups at work. After a few weeks of casual observation, it is usually clear who the malingerers are. Regular observation and perusal of laboratory notebooks also help to discourage dry-labbing, which is producing faked experimental results. Students can also be asked to assign part of the grade to the other students on their team. This procedure can work, but abuses can occur.

9.3.4. Advantages and Disadvantages of Laboratory Courses

Laboratory work can provide a concrete learning experience where principles can be discovered. The chance to design and possibly build equipment can serve as a marker event in the student's undergraduate career, and friendships developed in laboratory teams may last for years. In addition, a student may get to know his or her laboratory instructors better than any other professors, and may rely on them for advice and letters of recommendation.

Of course, everything is usually not ideal, and there can be disadvantages. The laboratory may be an incredible time sink as an overzealous professor tries to have the students learn everything about engineering in one course. The equipment may not work or may be obsolete. Files may be readily available, and dry-labbing of cookbook experiments may be rampant. A student's group may malfunction, leaving him or her with all the work and only one-third of the rewards. The professor may be absent, and the TAs may not speak English. Other than tradition, the reason for a laboratory course may be unclear.

The professor, whose task is to make the reality closer to the ideal, can have significant student contact and a chance to make a real difference in students' careers. Design laboratories often require a synthesis of the material from several courses. This helps the professor stay current in areas other than his or her research specialty. Working with real equipment can also help the professor be a better teacher of theoretical concepts.

Grading can be a chore when a number of long reports are turned in. It helps to have someone trained in technical communication available to grade the communication aspects of the reports and to work with students on their communication skills. This reduces the burden on the engineering professors and provides the students with better instruction. Unfortunately, the workload is often heavier in laboratories than in other courses, and less credit may be given for teaching laboratory courses. In the past this unfair workload was criticized by ASEE (1986).

From the departmental point of view excellent laboratories are a source of pride. If you don't believe this, visit a department with an excellent undergraduate laboratory and note the attitude of the professor who guides you through the laboratory. Excellent laboratories also help produce
well-prepared engineering graduates. And excellent laboratories are an advantage at accreditation time. Of course, the department gets what it pays for. Excellent laboratories require money for equipment, maintenance, a technician, and dedicated professors, who will remain dedicated only if suitably rewarded. Departments that neglect the laboratory as a way to save money when the budget is tight will pay the price of less-than-excellent laboratories fairly quickly.

9.3.5 Remote Laboratories

Remote laboratories are a relatively new development (Aktan et al., 1996) that have caught on rather quickly. In a remote laboratory setting students use a computer to control a live experiment that is in a different physical location. Students can use a remotely controlled camera to observe the experiment (Sanchez et al., 2004). Since many industrial facilities such as nuclear power plants, modern chemical plants, and robotic manufacturing are controlled remotely, use of remote laboratories provides students with experiences that can transfer to work settings. Remote laboratories allow institutions to share expensive equipment (Guo et al., 2007; Le Roux et al., 2010), reduce equipment down-time, and allow students to do the lab either synchronously (Feisel and Rosa, 2005) or asynchronously (Jernigan et al., 2009). Synchronous operation coupled with a video of the experiment in operation will feel most real to students; however, time on the apparatus will need to be scheduled in advance if the equipment is heavily used. Remote experiments should be used in conjunction with in-person labs since there are aspects of laboratory learning that are not well covered in remote labs. It is easier to impress the importance of safety and obtain compliance with in-person labs. Of course, remote labs will do a better job than in-person labs teaching students to operate in a remote environment.

Because of safety concerns, remote nuclear reactor experiments are run a bit differently than other remote labs. “It is the responsibility of the guest institution to make sure that experiments performed remotely on the host reactor are sufficient to meet their course objectives. On the other hand, all safety, security, and other regulatory considerations are mainly the responsibility of the host reactor. Therefore, the link between the host reactor and the guest institution should not allow access to any of the host reactor controls” (Malkawi and Al-Araidah, 2013, p. 514). Despite these restrictions a survey of their students after the students had been involved with a remote nuclear reactor experiment showed that the students thought the remote learning experience was comparable to on-campus face-to-face experiments.

One concern about remote labs is isolation of a student doing experiments alone (Feisel and Rosa, 2005). Isolation should be less of a problem than for students taking distance education courses on the computer because the student is tethered to the real world. In addition, it is relatively easy to have student groups do experiments (Hoyer et al., 2004).

Remote labs should not be confused with so-called virtual labs, which are a form of simulation (see Section 8.3.1). Virtual labs are particularly useful for asking “what if” questions for dangerous situations, but they are not a substitute for in-person or remote labs. When a simulation is used as a virtual lab these five principles need to be followed (Feisel and Rosa, 2005; Vaidyanath et al., 2007):

1. Include statistical variation of the correct order of magnitude.
2. Faithful to the actual experiment—run the experiment in real time.
3. Use the same pre-laboratory preparation and conference as with a real experiment.
4. User-friendly, well-documented software will allow students to run the virtual experiment asynchronously.
5. For an equivalent learning experience, require the students to calculate any parameter values that they would calculate for a real experiment.

The best of the virtual and real worlds can be obtained by having students run one or two real experiments and do related simulations (Heywood, 2005). A very recent modification of remote labs, augmented reality, combines real content with computer integrated virtual content (Andújar et al., 2011). Koretsky et al. (2011) found that combining simulation with real laboratories increased student learning. “Analyses of metacognitive statements of students show enhanced awareness of experimental design, greater references to critical thinking and higher order cognition in the virtual laboratory and an enhanced awareness of laboratory protocol in the physical laboratories.”

Although remote labs are not yet common in engineering education in most disciplines, they have become common in industrial electronics applications (Tawfik, 2013). Based on their economic advantages, we confidently predict that use of remote labs will increase significantly.

9.4. CHAPTER COMMENTS

Design and laboratory classes are important. They provide an opportunity for teaching professional skills critical for the successful practice of engineering. These include communication skills, management skills, and interpersonal skills. More engineers are removed from positions because of a deficiency in these skills than because of a lack of technical ability. Students learn by doing. However, the doing is more effective for learning if it is initially guided and supervised. Thus, we have included teaching procedures which specifically guide the student and provide feedback.

We enjoy teaching laboratory courses. The extra student contact makes up for the burden of grading laboratory reports. In addition, our school has done an adequate job of financing the laboratory and rewarding the participation of professors. Since we enjoy teaching laboratory classes, most students don’t mind taking them from us.

HOMEWORK

1. Determine what roles design and laboratory classes play in the curriculum at your school. Do they meet the spirit of the ABET requirements? If not, what can be done to improve them? Or, why do you think the ABET requirements are irrelevant?
2. Develop a plan to include design throughout the engineering curriculum at your school.
3. Choose one of the methods of teaching design. Outline how to incorporate this method into one of the design courses at your school. Explain how this method would help students achieve the course objectives.
4. Assume one of the design groups in your class is not functioning well. Develop an intervention strategy to help get this group back to healthy functioning.
5. Select appropriate objectives for a laboratory course at your school. Outline a structure to help students meet these objectives.
REFERENCES


Eastlake, C. N. (1986). Tell me, I’ll forget; show me, I’ll remember; Involve me, I’ll understand (The tangible benefit of labs in the undergraduate curriculum). *Proceedings of the ASEE Annual Conference* (Session 420). Washington, DC: ASEE.


