Chapter 7

Active, Cooperative, Problem-Based, Project-Based, Inquiry-Based and Service Learning

Chapter Learning Objectives

A. Define active, cooperative, problem-based, project-based, inquiry-based and service learning.
B. Provide examples of how these pedagogies can be used in a STEM course.

7.1 Active Learning (AL)

7.1.1 What is AL?

All learning is active, by necessity. The learner must do something in order to learn. For example, he/she must read a book, think about a concept, reflect in writing, solve a problem, design a piece of equipment, build a model, etc. With the exception of a formal laboratory setting, in the old paradigm students performed these activities almost exclusively outside the classroom. In the new paradigm, the term AL implies that these activities are also performed in the classroom under the guidance of the teacher.

7.1.2 Why use AL?

The advantage of having students perform various tasks in-class, such as problem solving, is that students have an opportunity to receive real-time coaching, an absolutely essential element in the learning process. Real-time coaching has been the norm in the teaching of sports and music forever. We would never think of teaching soccer using only demonstrations performed by a coach or have the players watch a video and then send them off to practice at home, on their own. Similarly, the main part of a guitar lesson, consists of the teacher providing real-time feedback to the student on how to sit properly, how to hold the instrument, and of course, how to play the particular piece of music.

Teaching engineering is no different. For example, when students learn how to solve problems, they must receive immediate feedback on their assumptions, approach, sketches, etc. This feedback may be given to them individually, if the class size allows it or to the entire group, if the class size is too large. For example, when I give my students a high-speed airflow problem and I notice, as I walk around the room, a large number of them using the incorrectly Bernoulli's equation instead of correcting each and every student, I call a time out from the problem and remind the class that Bernoulli's equation is not valid in compressible (i.e., high speed) flow. Alternately, and if the problem allows it, I may let students use Bernoulli's equation and arrive at a result that makes no sense.

When this happens, it is much more likely to leave them a lasting impression that any assumptions we make while solving engineering problems have serious implications in the accuracy and the validity of the results we get.

In addition to the real-time coaching, breaking up lectures with short AL exercises helps students stay focused for a longer period of time than simply listening to a lecture. Bonwell and Eison (1991) point out that the exclusive use of lecture in the classroom actually constraints students' learning.

7.1.3 How do we implement AL?

The following are just a few examples of how AL can be implemented individually in the classroom, at any time:

- Students take a few minutes to summarize in writing their understanding of a concept or answer a question.
- Students present a new concept, an application or the solution of a problem to the rest of the class.
- Students are given a problem to solve. The professor walks around the classroom, checking their work, answering questions, and providing guidance as necessary.

The benefits of AL can be enhanced if students have opportunities to perform some of these exercises in small teams. This is known as cooperative learning and is described in Section 7.2.

7.2 Cooperative Learning (CL)

Alone we can do so little; together we can do so much.
Helen Keller (1880 – 1968)

7.2.1 What is CL?

Johnson, Johnson and Smith (1991) define CL as instruction, which involves students working in teams to accomplish a common goal, under conditions that involve positive interdependence, face-to-face promotive interaction, individual as well as group accountability, team skills and group processing. These conditions distinguish CL from other forms of group work. A student team may have as a goal to understand material presented in class or in a textbook, solve a problem, perform an experiment, design a product/process, write a report, or even take an exam as a team. Team skills such as leadership, communication, conflict management and decision making, are essential for effective CL and must be taught and practiced just like any other academic skill.

7.2.2 Why use CL?

There are three good reasons for using CL in engineering classes.

A. It is now well documented that when implemented properly, CL increases faculty instructional productivity (Johnson, Johnson & Smith, 1991). While traditional teaching methods encourage students to work in isolation or even compete against each other, research shows that (a) competition in learning environments can be counterproductive (Kohn, 1992), and (b) the student-to-student interaction is one of the most effective ways to learn new material (Johnson & Johnson, 1991). This is partly because CL promotes higher order thinking skills in students (Johnson & Johnson, 1989).

B. In industry, most of the work is performed in teams. The ability to work effectively in a team is not acquired automatically. It takes interpersonal and social skills, which need to be developed and practiced. The expectation to function effectively on multidisciplinary teams has been articulated in Outcome d of the Engineering Criteria (ABET EC 2016-2017). Cooperative Learning offers opportunities for students to practice team and small group communication skills, which are absolutely essential for their success in the real world.

C. CL helps develop a sense of community in the classroom as well as outside the classroom. This improves student retention, especially in the freshman year (Tinto, 1994; Astin, 1993).

These reasons make it imperative that students work with each other in their efforts to achieve their educational goals.

7.2.3 Teamwork and CL

Cooperation is not a new idea. It has been the heart of interpersonal relationships, families, and socioeconomic systems since the appearance of mankind on earth. Hence CL is not an entirely new teaching technique. Actually, one look at traditionally taught classes reveals that group work has always been required for many assignments, such as laboratory experiments and design projects. However, even though group work is at the heart of CL, placing students in groups and telling them to work together does not always produce good results, simply because students do not know how to cooperate effectively. For example, group work in student projects usually results in a simple division of labor. While this is appropriate and necessary, students sometimes believe that they are responsible to learn only their own part. As a result, they interact very little with their teammates, usually just enough to patch together the various parts of their project report. This approach has the following pitfalls:

- It produces poor project results and reports because students do not spend enough time communicating with each other and collaborating on their project assignments.

- It leaves big gaps in the knowledge students acquire through the project because they do not take the time to discuss their individual pieces together.
- Students never get to see and appreciate the big picture because each only performs and learns a small part of the project.

It is clear then, that while group work is a prerequisite to CL, it does not guarantee enhanced learning. As Johnson and Johnson (1991) point out, for CL to occur, certain structural elements must be present to act as catalysts and help the students work with each other as a true team. When this happens, the output from each team is significantly higher than the sum of the individual contributions of the team members. These elements are discussed below.

7.2.4 Forming Teams

Size

Large teams provide a larger range of abilities, expertise, and skills available for a given task. In addition, there is a larger number of minds acquiring and processing information and hands available to perform the various tasks. On the other hand, larger teams require advanced social skills, which some students may not posses from the beginning. These skills include providing everyone with a chance to speak, coordinating the actions of team members, reaching consensus, ensuring explanation and elaboration of the material being learned, keeping all members on task, and maintaining good working relationships. Lack of these skills will result in a breakdown of the team process. Students in my classes have frequently expressed the opinion that three is the team size that works best for them. While teams of three may be ideal for most assignments, they are insufficient for big and demanding projects, such as National Design Competitions, simply because of the amount of work involved.

Membership

Teams should be as heterogeneous as possible to provide the best mix of abilities, sexes, ethnic groups, and learning styles/personalities. This enhances elaborate thinking, frequent giving and receiving of explanations, and perspective taking while discussing concepts or problems. In this kind of environment, team members will be able to contribute the skills of their most developed tools (learning styles) and learn from teammates whose excellence is in other areas. Heterogeneous teams prepare students for the workplace diversity of the 21st century, as they learn not only to understand and value their differences but also to use them constructively in the solution of engineering problems.

In my experience, student-selected teams tend to be very homogeneous, especially in terms of academic abilities and ethnic groups. This situation is not conducive to learning. For example, if you have a team consisting only of thinkers, little will be done.

If, on the other hand you have a team consisting only of (super) active learners, the outcome may miss the target because they want to start doing things without necessarily thinking about consequences. Similarly, in a team consisting only of feelers you will end up with much energy but also much drama.

Hence, it is necessary for faculty to intervene in the process of team formation. To ensure that my student teams are as heterogeneous as possible, I collect some background information from the students on the first day of class. A sample questionnaire is shown in Appendix A1. I then form the teams based on this information and the criteria discussed earlier. These teams provide students with a comfortable, family-like environment for performing various tasks, such as homework, design projects, and laboratory experiments throughout the term. As they spend time together, team members get to know each other better, feel safer and become comfortable taking risks within their teams.

On the other hand, for in-class CL activities such as problem solving, I often ask students to work with new partners. The intent is to promote a feeling of collaboration across the entire class, as students get to know more and more of their classmates.

7.2.5 Positive Interdependence

For CL to work, students must be given the message that either they will swim together or they will sink together. If the job is done well, everyone wins; if the job is done poorly, everyone loses. There is no way for an individual to succeed outside of the team, simply because the complexity of the task precludes this possibility. To enforce positive interdependence we set the expectation that each student has two responsibilities:

a. To learn his/her assigned material and perform his/her individual task.
b. To teach their material to all of their teammates.

These responsibilities must be clearly stated in the beginning of any assignment as a mutual goal for all team members. Students must understand that they are not done when they complete their part of an assignment. They are done only when everyone in the team has completed their part and everyone understands all the parts. A team-building activity that helps drives this point home is included in Appendix B1. Joint rewards may be used as an incentive to encourage positive interdependence. Examples are given below.

7.2.6 Individual Accountability

Anyone who has ever worked on a team is aware of 'free riders'. To avoid this problem and ensure individual accountability:

a. Keep team size small, at least in freshman and sophomore courses, when students' team skills are not yet fully developed.

b. Test students individually.

c. Structure assignments like 'jigsaw' puzzles. Each team member starts with one piece of the puzzle and in the end all members are responsible to know how the puzzle is put together. This approach is easily implemented in senior design courses because of the complexity of the projects. With some planning, it can also be implemented with less demanding learning activities, such as in-class team problem solving. For example, in a fluid mechanics course, when students are given a problem that requires integration of the three conservation laws (mass, momentum, and energy) each student in a team of three may be asked to take responsibility for applying one of the principles to the solution of the problem. Once this task is completed, students discuss how to integrate the three principles and complete the solution of the problem.

d. Each student maintains a personal 'notebook' or journal where they record all their contributions to the project. Each entry may take the form of a simple journal entry (e.g. 15 Sep. 2012: Searched in the library for articles relating to swept-forward wings – 2 hrs) as well as a summary of the actual work (e.g. list of articles found, 2-page summary of published work on swept-forward wings)

Individual accountability is the key to ensure that students benefit from CL. Without it, students may use the group as a crutch, without which they cannot function. The ultimate test in deciding whether CL has been effective in a class is the team members' ability to demonstrate that they can perform similar tasks by themselves.

7.2.7 Face-to-Face Promotive Interaction

An easily overlooked element is the chemistry that takes place, when two or more people are brought close to each other and asked to work together. The various interactions that take place, such as the verbal interchange, the mutual help and support, the encouraging, the explaining, all contribute greatly not only to the group dynamics but also to the growth of each individual. As students exchange ideas and opinions or discuss solutions, they influence each other's thinking and reasoning. At the same time, they provide instant feedback on each other's performance. A byproduct of all this 'face-to-face promotive interaction' is that unmotivated team members feel pressured to do their part.

One of the obstacles that often must be overcome in promoting this face-to-face interaction is the fact that most college classrooms are structured like the cabin of an airliner. This arrangement does not facilitate cooperation and it may affect student attitudes, as there is an implicit expectation that all information must come from the front of the classroom. Circular arrangements, where students can easily maintain eye contact with each other are best in this sense.

One of the issues raised over the years on a commuter campus like ours at SJSU, is students' limited availability for face-to-face team meetings. Many of our students work at least part-time or have family responsibilities, which prevent them from spending adequate time on campus to interact with other students. Online collaboration via email, although convenient, does not provide the same chemistry as face-to-face meetings. On the other hand, newer technologies (e.g. Skype) now allow face-to-face interaction from a distance. Although having all team members physically in the same room is always the best option, there are now attractive alternatives for face-to-face team meetings.

7.2.8 Team Processing

Teams rarely function perfectly well, whether the team members are students, faculty or engineers in industry. Actually, it is not uncommon for the productivity of a team to be less than the sum of the individual productivities of its members, if they were to work independently on the same task. Obviously, this is not an acceptable situation and it defeats the purpose for asking people to work on teams. One of the most effective ways to improve team performance is through team processing. Team processing consists of two parts:

a. The team members' reflection on how well the team works together.
b. The team members' recommendations on what can be done to improve their team performance.

A simple team processing activity at the end of a team session is to ask students to identify:

a. One or two things they did well while working together.
b. One thing each member did, which helped the team.
c. One or two things the team needs to improve, to be more efficient next time.

Student teams may then be asked to share some of their reflections and recommendations in class. The key to making this activity productive is to make sure teams are very specific when identifying both the positive and the negative aspects of their teamwork, so that they know exactly what works for them and what they must change. If done regularly, this activity has the potential to significantly improve team performance.

The following are examples of good and not-so-good reflections on the positive (+) and weak (–) aspects of team performance.

(+) We checked each other's work for errors and made sure that each member understood the whole problem and its solution. (–) We need to spend less time talking about things, which are not important for the solution of the problem. [good reflection]

(+) We solved the problem correctly. (–) We need to work faster. [not specific enough]

7.2.9 Professor as Facilitator

One of the challenges we face in implementing CL in our classes is our own insecurities. Standing in front of a board or a screen and talking for 50, 75 minutes or longer makes us feel in charge, regardless of how successful we are in helping students learn. It is also a very familiar model of teaching. In fact, for some of us it may well be the only model of teaching we have experienced as students in our undergraduate and graduate education.

With CL, a faculty member is still an authority on the subject matter and very much in charge of the teaching and learning process in the classroom. Part of each class session may still be used for lecturing. But CL also requires a change in thinking on the part of the faculty as well as on the part of the students. The faculty member should not be viewed as the only source of ideas and solutions. Students should learn to look for answers on their own to develop lifelong learning skills. Then problems/questions should be discussed within the teams. The faculty member should always be available as a consultant but he/she should be used as such only as a last resort. In lower division classes the professor may have to play also the role of the technical expert. In senior and graduate classes on the other hand, this role should gradually diminish, as students should learn to rely more on their own skills and on their teams and less on their professor. Only if the problem has been discussed extensively within a team and a resolution is not possible, should the professor step in and redirect the team's efforts.

7.2.10 In-Class CL

The success of a class meeting depends solely on how much it contributes to student achievement of CLOs. To a large extent, this success depends on meaningful student involvement during class through discussion of concepts and problem solving in small groups. Hence, AL and CL are important tools in increasing the number of students who achieve the CLOs.

Student involvement is much more meaningful if students come to class prepared. Hence, it is critical that students perceive reading assignments as essential to their effective participation in class activities and their successful completion of in-class assignments. As standard practice then, students should be expected to read ahead of time a few sections from the textbook or a related reference and attempt – on their own or in their teams – one or two problems. To enforce this point:

- Some classes could start with a short (10 min) quiz based on the assigned reading.
- In-class assignments (e.g. problems solved in small groups) are collected and graded.
- The scores on these quizzes and problems contribute in some way towards the final course grade.

Typical in-class assignments that lend themselves for CL in engineering courses include problem solving, case studies, laboratory experiments, design projects, and research projects. Examples of how CL can be structured effectively in each of these are given below.

In-Class Team Problem Solving

Problem solving is the bread and butter of any typical, junior-level engineering course, whether the field is aerospace, civil, or environmental engineering. As we have seen, demonstrating the solution of example problems on the board is certainly a necessary step in the learning process. However, by itself it is never sufficient to ensure student development of problem solving skills. Students also need to solve problems (approximate) under supervised conditions, to ensure they receive appropriate feedback from peers and experts. In-class CL problem solving sessions offer an ideal environment for satisfying these conditions and may be structured as follows:

a. A short lecture (~15 min) introduces a topic, including one or two example problems illustrating key points.
b. Students may ask questions during as well as immediately after the short lecture.
c. Students are given a similar problem to think about individually and quietly (3 min). This short time will allow reflective learners to come up to speed before engaging in discussion with their teammates. In fact, this time will benefit any type of learner by giving them an opportunity to organize their thoughts.
d. Students work in teams of three (with new partners every time) to solve a similar problem (15 min). The time allowed may vary depending on the difficulty of the problem. The faculty member walks around the room encouraging each team, giving them hints and answering questions.
e. Upon completion, each team turns in their solution. A team member's name on the solution sheet implies that he/she has participated in and understands the solution of the problem and may be called to present it to the rest of the class. To enforce positive interdependence and individual accountability, any team member may be called randomly to present their team's solution. Students understand that failure to do so will result in a grade of 'no credit' for the entire team for this particular problem.
f. For challenging problems or when several teams are experiencing difficulties, a team or the faculty member may present the solution on the board and/or handouts of the solution may be distributed.
g. The process is repeated with a short lecture on the next topic followed by a problem-solving session in teams.

It is important that collected problems are graded and the scores contribute somehow to each student's grade in the course. This will motivate students to take these activities seriously and come to class prepared.

One may ask what to do with teams that solve a problem correctly before the allotted time and can demonstrate that all their members understand the solution. Depending on the situation, they may be asked to do one of the following:

a. Answer a new, more challenging question on the same problem.
b. Solve a new problem.
c. Coach other teams to solve the original problem.

Options (a) and (b) allow a faculty member to teach a class at different levels, based on individual capabilities. Thus, more capable students do not become bored in class by waiting for everyone else to finish. Option (c) avoids the negative effects of competition among teams and helps foster a spirit of cooperation among all students in the class. Moreover, it benefits the students who coach other students in many ways, one of which is by enhancing their communication skills. For large classes this approach can be very helpful to a faculty member who does not have enough time to talk to each and every team. On the other hand, one must be sensitive to the fact that some teams may not wish to be 'coached' by other students; rather they may prefer to solve the problem on their own. These teams may be allowed to finish the problem outside of class and turn in their solution at the next class meeting.

Case Studies

If done properly, case studies can be used to address several of the eleven outcomes in Criterion 3 of the Engineering Criteria (ABET EC 2012-2013). For example, case studies in engineering failures may address Outcome c (engineering design), Outcome d (multidisciplinary teaming), Outcome f (professionalism and ethics), Outcome g (communication skills), Outcome h (global and societal issues), Outcome i (lifelong learning skills), and Outcome j (contemporary issues). A CL approach to teaching case studies, may be structured as follows:

- For each case study, a student team is assigned to research the background information and give a 15-minute presentation in class.
- Following this presentation in class, students spend 10 minutes in teams discussing questions related to the issues raised and summarize their team's position in writing.
- Team members are selected randomly to share their team's insights with the rest of the class.
- Students follow up after class with individual and/or team written assignments, in which they analyze situations and/or provide best course of action for certain scenarios.

Hoover, Fowler, and Stearman present several aerospace engineering case studies that involve safety, ethics, and liability issues related to airplane and spacecraft accidents, as well as a methodology for constructing such case studies.

7.2.11 In the Lab CL

Laboratory experiments in science and engineering have traditionally been performed in small groups. However, personal experience has shown that the traditional approach presents the following challenges:

- Students often come to the lab unprepared and waste precious time trying to figure out simple things such as, what exactly they need to measure, which parameters they need to vary and how much, and how many data points they need for each measurement.
- After the lab, students divide the report into sections, with each group member taking responsibility for completing one of these sections. As a consequence, students never see the big picture and lab reports tend to be in-cohesive documents patched together at the last minute with no group discussion and no editing.

These challenges can be overcome by:

- Proper 'design' for each experiment, as required by Outcome b (ABET EC 2016-2017). Each team submits their design-of-experiment a week before their assigned time in the lab, allowing enough time for faculty input and corrections as necessary.
- Individual pre-lab tests with questions that pertain to the particular experiment. This ensures that each and every student understands the theory of the experiment and is prepared to meaningfully contribute in the lab. To enforce individual and team accountability, each and every student must score at least 80% on the pre-lab test otherwise the team is not allowed to perform the experiment.
- Student teams present their results in class or in the lab (after they have had an opportunity to process their data and write their reports) and are quizzed individually on their findings.

7.2.12 CL in Projects

The senior design is the most representative project experience in engineering schools. In aerospace engineering for example, the capstone, senior design, two-semester course sequence typically involves an aircraft or a spacecraft design project. Popular among students are projects that involve participation in national design-build-test competitions sponsored by professional organizations. For example, AIAA and SAE sponsor annual competitions that involve the design, manufacture, and flying testing of airplanes that meet specific mission requirements. These projects tend to be quite challenging and demanding in terms of required man-hours, especially during the second semester when students have to build and test their projects.

To ensure successful and timely completion, larger teams are more appropriate for such projects. However, problems similar to the ones experienced in laboratory courses are common in senior design courses as well. For example, by focusing on individual tasks, students are often ignorant of the work done by their teammates, even though they work together towards the same goals. As a result, each student achieves only a small subset of the CLOs, depending on the particular task they chose to perform. Moreover, the problem described earlier with lab reports is also found with project reports: they consist of individual contributions put together at the last minute with no team discussion and no proper editing.

Some ideas for ensuring individual accountability are:

Individual quizzes: They may be given anytime during the course to test knowledge of basic design issues. The scores students receive in these quizzes contribute toward their final grades.

Individual oral exams: When student teams present their projects, each student is responsible to know how each and every part of the design process has been carried out, not only the parts they have individually completed. Moreover, students are asked questions that pertain to theory and the design process.

Personal notebooks: Each student is required to maintain a notebook, which is worth 10% of the grade. All calculations, plots and graphs, sketches, and anything the student does as part of the project, are dated and collected in a binder to be presented upon request any time during the course.

7.2.13 What About "Covering" the Material?

A common concern often expressed by faculty members from every field is that allowing students to participate actively in the classroom, takes away time from lecturing. As a result, we cannot "cover" material that is important to include in the course. After all, lecturing is the most effective way for delivering a large body of information to students or is it?

Course material is definitely important, as it contains the specific knowledge that defines each field. One can argue, however, that far more important, is the skill level that students acquire in relationship to this material. From this perspective, the course material is not the end in itself but rather the vehicle that is used to help students develop the skills specified in the CLOs. Speeding through a course with the ultimate goal of "covering" the book will result at best in superficial knowledge of the material (levels 1-3 in Bloom's Taxonomy). Most of us would agree that this kind of knowledge is of little value in the real world. In fact, as we often observe when teaching courses with prerequisites, this kind of knowledge is even insufficient to carry a student to the next course. To become effective professionals, students need "working knowledge" of the material, which implies ability to (a) integrate material from various subjects and (b) apply what they learn in challenging, real world situations, with brand new context. This level of knowledge, however, requires real time "coaching", which can only take place effectively and efficiently during class.

But is less material "coverage" a necessary evil of an active classroom? Not really. The deciding factor in covering more or less material in a given course is the preparation, receptivity, and enthusiasm (or lack there of) of the students. These factors should be used to judge the pace of any course, regardless of whether it is delivered through lectures or AL. Moreover, students can easily acquire levels 1 and 2 knowledge on their own time, outside of class. Where we, as experts, are needed the most, is in "coaching" students to master higher-level skills (e.g. ability to tackle open-ended problems, design a new product, etc.). It makes sense then, that most of our class time should be devoted to this task and as research has shown repeatedly, AL and CL can be very effective tools on our side.

In conclusion, it is not necessary to compromise quantity simply because AL and CL are used during class but even if this is the case, CL will produce students with much better engineering skills.

7.3 Flipped Classroom (FC)

7.3.1 What is FC?

Traditionally, during class students listen to lectures. Afterwards, on their own time, they attempt to apply concepts from these lectures to problem solving, experiments or design activities, alone or in groups. In a FC the sequence of these events is reversed, namely, students watch video lectures on their own time before class; during class they solve problems, engage in discussions or participate in design activities under the guidance of a faculty member.

Although the term FC was introduced in 2000, the idea is not new. For example, humanities faculty have traditionally run their classes on the expectation that students read books at home and come to class prepared for discussion. The term, however, sounds rather radical in engineering and science, as over the years a culture of passivity in the classroom has been developed and students expect new concepts to be introduced first during lectures.

7.3.2 Why FC?

The advantages of meaningfully engaging students in the classroom through problem solving and other activities were discussed in Sections 7.1.2 and 7.2.2. A flipped classroom takes AL and CL to a new level by formalizing the expectation that students will learn basic concepts on their own time, while providing additional resources (e.g. online videos). Hence, if done correctly, FC has the potential to bring students to much higher levels of learning by freeing precious class time for pursuing more difficult learning tasks, while working in teams under the guidance of a faculty member.

Velegol, Zappe & Mahoney (March/April 2015) found that 77% of the students preferred the flipped classroom compared to the traditional lecture because they (a) enjoyed the flexibility of learning new concepts on their own time and in their own way, (b) were able to review lectures as needed, and (c) valued the interaction with faculty and students during class time.

7.3.3 How do we Implement FC?

a. Student preparation before coming to class: This is critical for the success of a FC, just like in AL and CL (Section 7.2.10). Students are again expected to read ahead of time a few sections from the textbook or course notes. In addition, a typical FC includes short videos (each approximately ten minutes or less). Students may have to view several of these short videos before a particular class session. Just like in AL and CL, students may also be expected to attempt, on their own or in teams, one or two problems.

b. Regular assessment of student learning: This is critical to ensure that students indeed understand the material in the lectures, the notes or the textbook. Short online quizzes can be set up for this purpose in a way that a faculty member can easily review a summary of the results as well as individual student responses before going to class.

c. Summary of key concepts: The first ten to twenty minutes of each class is spent reviewing and summarizing key concepts. This is also a good time to allow for any questions students may have from the lectures or their reading. Any more class time spent on review may inadvertently give students the message that viewing the lectures online and reading the notes before coming to class is not really necessary.

d. Students work in teams to solve problems or design an engineering artifact: Just like in AL and CL this is the most important part of the cycle, as it gives students an opportunity to apply what they have learned into a real-life problem while working with fellow students under the supervision of an expert. Again, the faculty member walks around the room encouraging each team, giving hints and answering questions. Occasionally, the faculty member may stop the class to address a common question or misunderstanding. A FC may fail and students may become frustrated, if there is no adequate help and coaching during class. After all, if students could learn everything they needed to know by reading the textbook or the course notes and viewing mini lectures online and could tackle any problem we give them in class without our help, there would be no need for a faculty member to be involved in such a course.

e. Students work is collected, graded, and constitutes a significant part of the course grade: This will ensure that students take their in-class assignments seriously and work diligently to complete them during class time. It also increases their motivation to come to class prepared. As discussed in Section 7.2.10, teams, which do not finish their assignment on time may be allowed to turn them in at the beginning of the following class meeting, perhaps with a reduction in the maximum score possible.

7.4 Flipped Learning (FL)

7.4.1 What is FL?

Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space (classroom) to the individual learning space (outside the classroom), and the resulting group space is transformed into a dynamic, interactive learning environment where the instructor guides students as they apply concepts and engage creatively in the subject matter (FLIP Learning, 2014).

7.4.2 Why FL?

In addition to the advantages mentioned in Section 7.2.2, FL, if implemented correctly, would free up precious class time and allow students to focus on more complex tasks under the supervision and coaching of the instructor. This would facilitate students' development of higher order thinking skills.

7.4.3 How do we Implement FL?

As was the case with CL (see Sections 7.2.3 - 7.2.9), to make FL work effectively, instructors must put in place certain elements or pillars (adapted from FLIP Learning, 2014). These elements, described below, distinguish FL from FC.

a. Flexibility in space and time - Instructors may physically rearrange their learning spaces to allow for students working independently (AL, Section 7.1) or in teams (CL, Section 7.2) depending on the particular topic or set of skills they are teaching. In addition, students have some freedom to choose when and where to learn these skills (see Section 2.5). This kind of flexibility in student timelines for learning requires in turn a flexibility in faculty timelines for assessment of student learning.

b. Learner-centered model of learning - Students spend their class time alone (AL) or in teams (CL) exploring topics in greater depth and carrying out complex tasks, such as open-ended problem solving and/or design. Furthermore, students are given opportunities to reflect on their learning in a manner that is personally meaningful.

c. Intentional Content - Planning is key in making FL work. Session learning objectives spell out specific skills, which students are expected to acquire. These may be conceptual, procedural or both. Instructors then choose particular pedagogical models and in-class assignments to help students develop specifically these skills.

d. Professional Educator - As instructors, we must digest the fact that that our primary responsibility in a course is to ensure student achievement of CLOs. To this end, we must do whatever it takes to make this happen. Our role as facilitators and coaches in the FC/FL model is far more important and more demanding than our role as lecturers in the traditional model. During class time we must continually observe students, provide them with real-time feedback (see Section 2.8), and assess their work. Just like we expect students to reflect on their learning process, we must also be reflective in our own practice to reach an understanding, after several iterations, of what works and what doesn't in our classrooms and make adjustments as necessary. Just like we expect students to work in teams, we must also connect with each other to improve our teaching and accept constructive criticism from peers or significant others when warranted. Last but not least, we need to learn how to live with and control a certain amount of classroom chaos, which comes with the territory of team-based, student-centered learning. It may seem that retreating in the background of an active classroom makes us less visibly prominent, however, we must never forget that our effectiveness in facilitating student learning during class is an ingredient without which FL cannot work.

7.5 Problem–Based Learning (PBL)

7.5.1 What is PBL?

In the traditional teaching approach, students are first presented with a theory and then with problems to solve, based on this theory. In the PBL approach, on the other hand, students are first presented with a problem. The problem is usually open-ended and realistic, keeping students engaged and serving as a point of focus for anything students need to learn. The complexity of the problem typically requires students to work in teams, to accomplish the following tasks:

a. Organize their ideas and previous knowledge as they relate to the problem.
b. Pose questions on aspects of the problem they do not understand.
c. Come up with a list of things they need to learn in order to solve the problem.
d. Learn these things on their own or with the help of other experts.
e. Apply their new knowledge to the solution of the problem.

Unlike the traditional approach, in which faculty act as the only experts in the classroom, in PBL faculty act more as coaches and facilitators and they:

a. Answer student questions related to the problem.
b. Prompt students with questions.
c. Direct students to appropriate sources of information.
d. Provide guidance as necessary, to ensure students stay on the right track.
e. Assess student learning during the problem solving (formative assessment) process as well as at the end (summative assessment).

7.5.2 Why use PBL?

In PBL students learn things as they become necessary for the solution of their problem. This is in contrast to the linear way of presenting material in most university courses and texts, where the instruction is topic-driven. Topic-driven instruction is logical for someone who already understands the subject; it is not necessarily logical for someone who is trying to learn the subject. Hence, an inherent benefit of PBL is that it allows students to learn new material in ways that seem more natural, dictated by a need rather than by the sequence in a book. This approach is also known as ***Just-In-Time Learning***.

The PBL approach was developed in its modern form at the McMaster University Medical School in the 1970s. Due to its success in medicine, PBL has been adapted in other fields of higher education (Rhem, 1998). In particular, it has been proposed as an approach with excellent potential for developing the critical problem solving skills and many of the "soft" skills (e.g. communication and team skills) required by ABET EC 2000 (Rugarcia et al, 2000). Many engineering courses around the world currently use PBL with success (Brodeur et al, 2002; Mills and Treagust, 2003; Yusof et al, 2004). In fact, some schools have structured their engineering programs entirely on the PBL approach (Kolmos, 2006).

Open-ended problems (OEPs) are an integral part of PBL. A related methodology, recently adapted from mathematics education, is model-eliciting activities (MEA). MEA also involve OEPs set in a realistic context. They were recently introduced in engineering education as a way to help students become better problem solvers, as well as a vehicle for increasing interest and engagement in underrepresented student populations (Diefes-Dux et al, 2004a; Diefes-Dux et al, 2004b; Moore & Diefes-Dux, 2004; Moore, 2008).

7.5.3 How do we implement PBL?

Obviously, not every problem given to students needs to be open-ended. Students still need to start with simple exercises and solve many such exercises in each topic to get a feel of how to use appropriate modeling in engineering and apply the various principles and equations they learn in each course. I find that three or four OEPs in each course are adequate to help students develop OEP solving skills.

One of the greatest difficulties in approaching OPEs is the lack of a structured approach or algorithm to guide students through the solution. This is especially challenging for sensing and sequential learners. I have found Woods' Problem-Solving Methodology (PSM) an excellent tool for circumventing this difficulty (Woods, 1994). This process includes seven steps, which are described below.

Step 1: Engage

Engagement was established in Chapter 2 as one of the conditions for learning; it is also the first step of the PSM. Students will engage in a problem if they are convinced they can solve it and if they see it as having some relevance to their own lives (Cambourne, 1988; Mourtos, 2003).

Step 2: Define

In Step 2 students try to understand the problem and re-state it in their own terms. They make a comprehensive list of what is given but also what may be known from other sources, and determine any applicable constraints. This step usually requires some research to gain additional background about the problem. For example, students may have to read various sections of the textbook, visit the library or, as is much more common these days, search online. Students are expected to draw a sketch of how they visualize the problem including any parameters they think are relevant. The most important outcome of this step is the criterion to be used in answering the question. For example, in a fluid mechanics OEP, students are given a leaking soccer ball and asked if it is going to be playable (i.e. noticeably softer) after the first half of the game. To define the problem in proper technical terms students need to decide what "measure" they will use to determine if the ball will be playable (e.g. percent of air mass escaped, percent of pressure lost, percent of air density reduction, etc.).

Step 3: Explore

In this step students explore relevant questions related to the problem and brainstorm possible ways to model the physical situation by making appropriate assumptions. By making these assumptions, the students in essence select a physical model for the problem. To develop intuition, students also attempt to predict the answer to the problem.

Step 4: Plan

Students follow up with an appropriate mathematical model (usually the simplest available) for developing a solution. They break down the problem into smaller sub-problems, each involving the calculation of various parameters, which serve as stepping-stones towards the final answer. It is important that students develop an algorithm (flow chart) for the solution of the problem and not substitute any numerical values. This algorithm may involve, for example, identifying appropriate equations or graphs for calculating various parameters in each sub-problem.

Step 5: Implement

This is the most straightforward step of the PSM. Students simply substitute the values of known and assumed quantities into their equations and develop the solution, checking for accuracy and consistency of units along the way. The outcome of this step includes numerical answers for various parameters and may also include additional sketches, figures, or drawings.

Step 6: Check

Students check their calculations for errors and make sure the units in all parameters are correct.

Step 7: Reflect

Choosing an unrealistic physical model in Step 3 or using an incorrect mathematical model in Step 4 will inadvertently result in answers that do not make sense. This is a common occurrence in OEPs even among experienced problem-solvers. Students are expected to identify the cause of the problem and correct it or suggest a more sophisticated model to solve the problem. Furthermore, they compare their answer to their guesstimate from Step 3. If their guesstimate was incorrect they provide an explanation as a way of developing intuition. In addition to discussing the solution of the problem, students also reflect on their own strengths and weaknesses in the problem-solving process. More importantly, they are expected to come up with a plan for removing these weaknesses in the future.

As Woods (1994) points out, the reflection is usually not done very well, if done at all. Yet, this step is critical for self-assessment and self-improvement.

7.6 Project–Based Learning (PjBL)

7.6.1 What is PjBL?

PjBL is an extension of PBL to more challenging, interdisciplinary, real world problems and as such, offers opportunities for meaningful employment of whatever students are learning. Just like in PBL and IBL, students work in teams and are in charge of the learning process, while the faculty member's role is to provide guidance, as necessary.

7.6.2 Why use PjBL?

In addition to the benefits mentioned earlier under PBL:

a. Students acquire multidisciplinary problem-solving skills, including an ability to see problems from a broader perspective.
b. Students solve real world problems and often produce equipment that is of practical use (e.g. a new experiment for an instructional or a research laboratory).
c. Students produce work that is often publishable in student or even in professional journals. Moreover, they may present their work in conferences.
d. Capable, motivated undergraduates have an opportunity to engage in research work under the supervision of two or more faculty members as part of their coursework.

e. PjBL allows for a flexible curriculum integration, which helps students see the connection between the different courses they are taking (Mourtos, Papadopoulos & Agrawal, 2006).
f. Faculty members who supervise such projects become more aware of material taught in other courses and often see opportunities for collaboration in multidisciplinary research projects with their colleagues.

7.6.3 How do we implement PjBL?

Projects may be limited to the content of a particular course. For example, in an aerospace propulsion course students may work in teams to design a subsonic axial compressor, an axial turbine, and match the two for placement in a jet engine with given specifications (Hill & Peterson, 1992). An even better approach is to design projects that require integration of theory and applications from two or more courses (Mourtos, Papadopoulos & Agrawal, 2006). Student engagement increases substantially if students are allowed to identify, research, and formulate projects based on their interests. For example, a few years ago a student team in my aerodynamics course decided to explore the formation flight of commercial aircraft, as a way of decreasing drag, fuel consumption, and engine exhaust emissions. Their project integrated principles from aerodynamics as well as flight mechanics, courses that students were taking concurrently. Another team in my compressible flow course designed the inlet of a ramjet engine. Naturally, their project required a thermodynamic analysis of the engine, which is a topic discussed in our propulsion course.

It should be noted that it is not necessary for students to be enrolled concurrently in the courses from which they draw content. Some students may have taken one of the courses already, while others may plan to take one of the courses in subsequent terms. On the other hand, this approach will work much better if students happen to be taking two or three courses concurrently, and the faculty members who teach these courses design and coordinate a joined, interdisciplinary project.

7.7 Service - Learning (SL)

7.7.1 What is SL?

Jacoby et al (1996) define SL as *a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities intentionally designed to promote student-learning and development*. SL integrates meaningful community service with formal instruction and reflection for the purpose of (a) enriching students' learning experience, (b) increasing students' civic awareness, and (c) meeting the needs of local communities.

7.7.2 Why use SL?

a. Just like PBL and PjBL, SL has the potential to play a significant role in meeting EC 2000 (The Accreditation Board for Engineering and Technology, 2016-2017), as it provides a mechanism for integrating technical and non-technical skills in any engineering course.

b. SL increases engineering students' motivation, retention, and graduation rates, especially among women and under-represented minorities (Astin, Vogelgesang, Ikeda, & Yee, 2000; Ropers-Huilman, Carwile & Lima, 2005; Bringle, Hatcher & Muthiah, 2010). Astin, Vogelgesang, Ekeda & Yee (2000) performed a longitudinal study in which they tracked more than 22,000 undergraduate students from various undergraduate institutions across the US, in an effort to explore the effects of SL on the cognitive and affective development of students. They concluded that student participation in SL had a measurable positive effect on their degree of interest in their subject matter, GPA, writing skills, critical thinking, values (e.g. promoting racial understanding), self-efficacy, and leadership. Furthermore, they found that students who participated in SL projects were more likely to participate in service upon graduation and even seek a career in public service. This finding is significant, as it shows that the impact of participating in even small SL projects can have a lifelong impact on a student's life outlook regardless of his/her original career choice.

c. There are tremendous benefits to the communities served through these projects. For example, K-12 students, who are served through SL projects are exposed to science and engineering and view engineering students as role models, increasing the confidence of the former to strive towards college and pursue a career in STEAM.

7.7.3 How do we implement SL?

Capstone, senior design courses constitute a great venue for integrating SL into engineering curricula, and many schools have successfully implemented such projects (Tsang, 2000). First-year courses, which introduce engineering design to freshmen, provide yet another opportunity (Lord, 1999; Tsang 2000; Budny, Lund & Khanna, 2013). On the other hand, SL programs like EPICS have grown into multi-university collaborations, with vertically integrated long-term, large-scale, multidisciplinary design projects, in which undergraduate student teams work closely with not-for-profit organizations across the US to deliver projects of significant benefits to local communities (Coyle, Jamieson & Oakes, 2005). It is worth noting that students may participate in EPICS projects for up to seven semesters, allowing them for a more complete and meaningful experience. Finally, organizations like Engineers Without Borders, which have chapters in many engineering schools, emphasize projects that serve the needs of communities in developing countries around the world, helping students become more culturally aware and better prepared to become responsible professionals in a globalized world. These examples show that SL can be integrated successfully into any engineering course or combination of courses at any level, allowing students for meaningful, real-world engineering experiences.

For example, for the past few years my aerodynamics students design, build, and present hands-on exhibits that illustrate engineering concepts to an after school program for elementary students as well as to local high schools. In addition to promoting STEAM education, my students serve as role models for elementary, middle or high school students from economically disadvantaged and ethnically diverse student populations, who may not know anyone who has gone to college.

7.8 Inquiry-Based Learning (IBL)

7.8.1 What is IBL?

IBL is a form of AL and a relative of PBL. Although one may find a variety of IBL definitions in the literature, in general the term implies that students are provided with a general statement of purpose (goal) for a research question and their task is to design a procedure (method) for getting an answer. Naturally, they are also expected to communicate their results.

7.8.2 Why use IBL?

IBL is an ideal approach for developing laboratory skills, like those prescribed in Outcome b of EC 2000 (The Accreditation Board for Engineering and Technology, 2016-2017). To illustrate this, we use the inquiry continuum (adapted from Middle School Systemic Change Partnership, 2003) in Table 7.1, as a tool to understand the process and the skills needed to design an engineering experiment. As we move from the left end of the continuum (cookbook lab) to the right (student-directed/student-designed lab), the responsibility for the various tasks outlined on the left column gradually shifts from the professor to the student. This is an important observation because as we have seen, taking responsibility for one's own learning is one of the eight conditions that must be satisfied in order to master any learning task. Hence, without an opportunity to take responsibility for the decisions involving the various tasks of an experiment, students cannot be expected to learn how to develop laboratory skills.

7.8.3 How do we implement IBL?

To better explain how to setup experiments that allow students more responsibility in the lab, I will use an example from my aerodynamic courses. One of the experiments I ask students to design is a wind tunnel study of the performance of the Clark Y-14 airfoil, simply because this is the airfoil that came with our wind tunnel. Students use the following steps to design their experiment:

Define – Students already know from theory that airfoil performance is a function of angle-of-attack and Reynolds number, a dimensionless parameter defined as $\mathrm{Re} = \dfrac{\rho V c}{\mu}$, where ρ, V, and μ are respectively the density, speed, and molecular viscosity of the air in the wind tunnel test-section, and c is the airfoil chord length. However, they must define "airfoil performance" in more specific terms, so they can measure it in the lab. Thus, they generate the following questions, the answers to which form the objectives of the experiment (Figures 7.1 and 7.2):

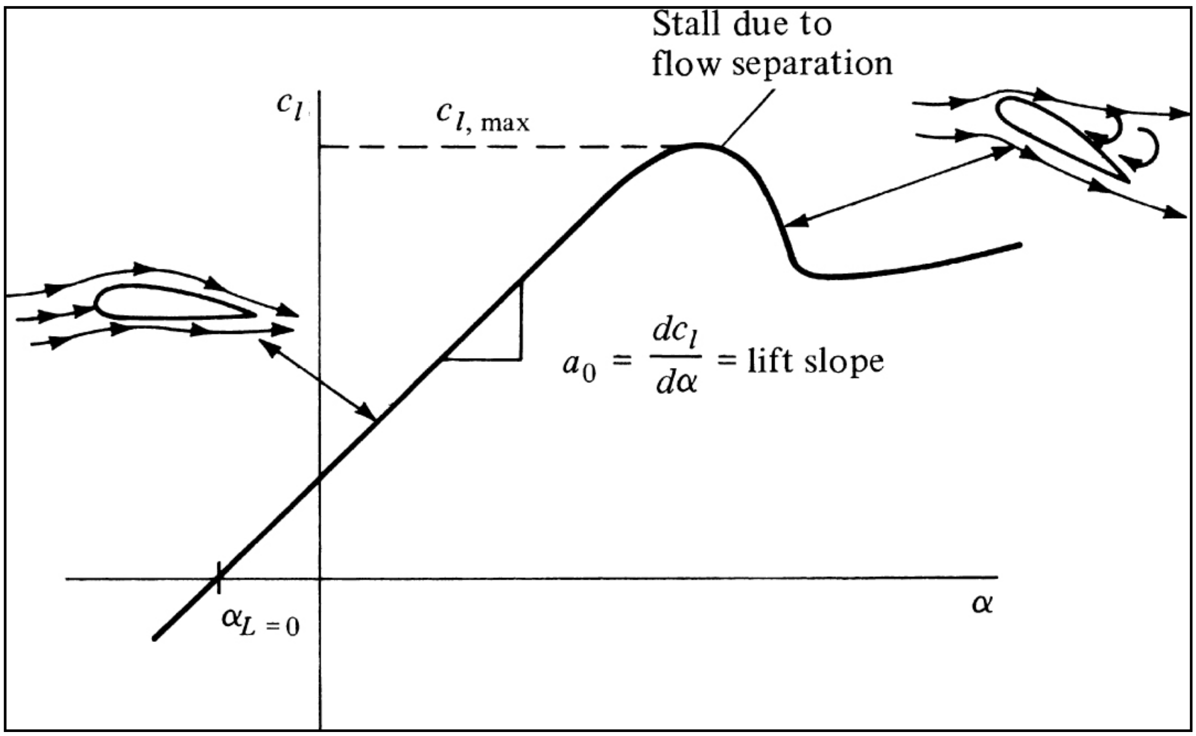

Figure 7.1 - Typical airfoil lift characteristics shown on a lift coefficient versus angle-of-attack curve.

a. How much lift does the airfoil generate at different angles-of-attack and Re?
b. At what angle-of-attack does the airfoil stall?
c. At what angle-of-attack does the airfoil produce zero lift?
d. What is the maximum lift coefficient of the airfoil? Does it change with Re?
e. What is the lift slope of the airfoil?

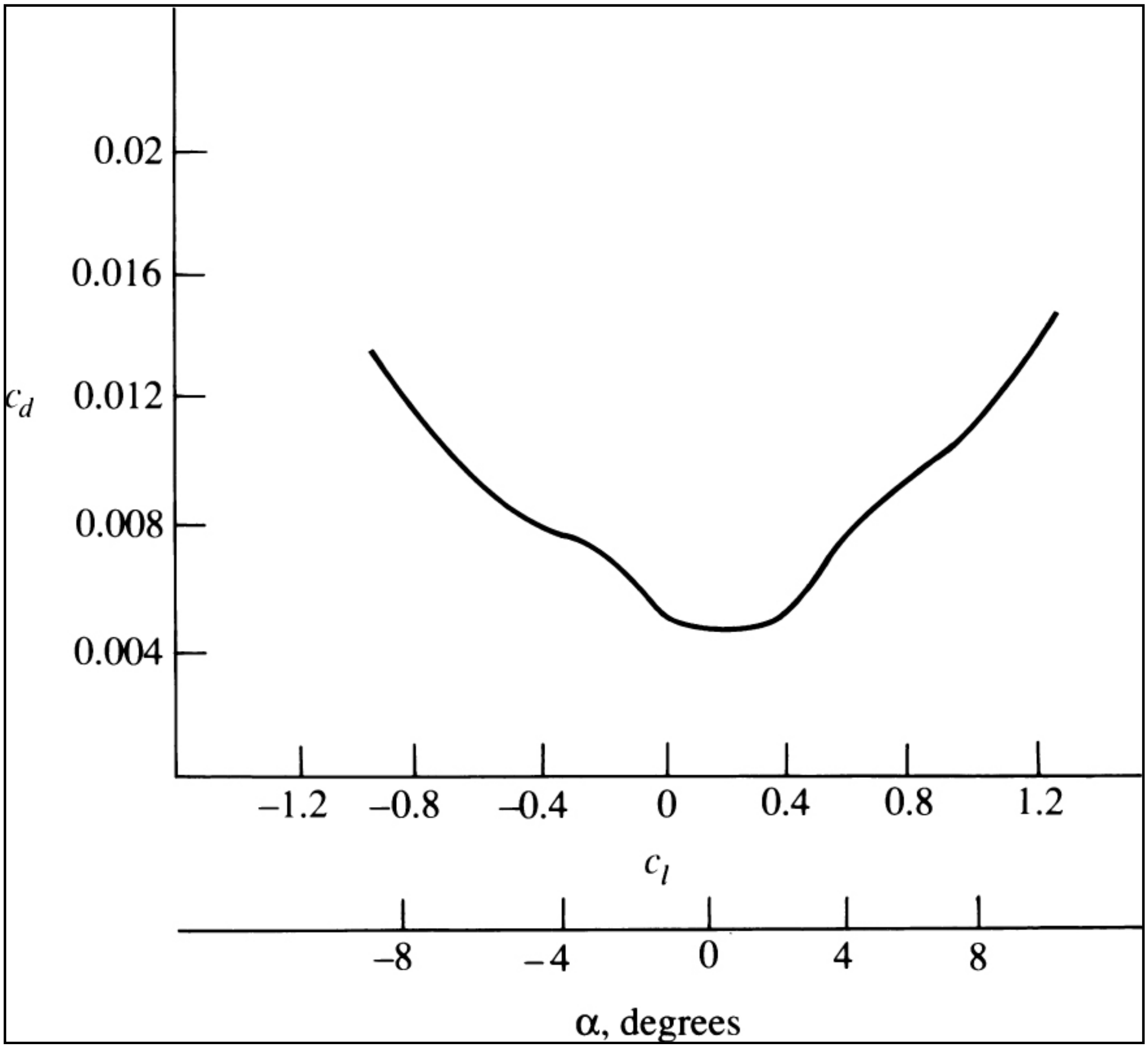

Figure 7.2 - Typical airfoil drag characteristics shown on a drag coefficient versus lift coefficient (or angle-of-attack) curve, also known as the "drag bucket" of the airfoil.

a. How much drag does the airfoil generate at different angles-of-attack and Re?
b. What is the lowest possible drag of this airfoil?
c. For what range of angles-of-attack does the airfoil give reasonably low drag (i.e., what does the drag bucket of the airfoil look like?)
d. What is the best lift-to-drag ratio we can expect from this airfoil?

Research – Students can find in their aerodynamics text a theoretical relationship between the lift coefficient and angle-of-attack for thin airfoils. There are no theoretical predictions for the drag of an airfoil. However, students are expected to search for previously published data for the particular airfoil. They can easily find the lift and drag characteristics of the airfoil as well as surface pressure distributions for different Re. As part of their research, students also run a computer program, which predicts the pressure distribution, lift and drag of the airfoil as functions of the angle-of-attack. This step sets up the stage about what to expect from their measurements in the wind tunnel.

Select variables – Students identify the lift and drag of the airfoil as the dependent variables of interest and the angle-of-attack and the test-section airspeed V – which determines Re – as the independent variables in their experiment.

Select appropriate methods – Students identify two methods for measuring each of the two aerodynamic forces. The lift can be found by (a) integration of measured pressure distributions on the surface of the airfoil and (b) direct measurements from a dynamometer. The drag can be found by (a) using Newton's 2nd law to calculate the momentum loss in the wake behind the airfoil and (b) direct drag measurements from the dynamometer.

Choose equipment and instrumentation – Students may use a model with perforations (static ports) to measure pressure distributions on the surface of the airfoil. Pressure distributions may be taken either with pressure sensors or with a multi-tube manometer. The pressure sensors constitute a part of a data acquisition system, which allows real-time plotting of the pressure distribution on a computer screen. However, the accuracy and repeatability of the measurements is sometimes questionable. The multi-tube manometer is a more primitive, yet more direct method and therefore less prone to error. Students discuss the pros and cons of each and choose one of the two methods. Some teams use both methods for comparison purposes as well as for redundancy. Students use a different model of the same airfoil with a dynamometer for direct lift and drag measurements. Finally, they use a pitot tube for measuring wake traverses (airspeed) behind the airfoil.

Select the range of the independent variables – A careful study of published experimental data reveals that the (maximum) lift and (minimum) drag of an airfoil depend on Re, however, the variation of Re must be significant (e.g. from 10^3–10^6 or from 10^6–10^9) to measure a drastic change in maximum lift and/or minimum drag. Students quickly find out that changing the test section airspeed from the lowest possible value to the highest gives only a narrow range of Re, which is not enough to explore Re effects. In regards to the range of angle-of-attack, the key is to (a) collect data for a sufficient number of angles (say 8–10) to be able to reproduce a lift curve that looks like the one in Figure 7.1 and calculate the lift slope, (b) choose several negative angles-of-attack (from -1^0 to -6^0) to capture the zero lift angle of the airfoil $\left(\alpha_{l0}\right)$ and (c) choose several angles in the range between 12^0–20^0, to capture the stall angle $\left(\alpha_s\right)$ and the maximum lift coefficient $\left(c_{l_{\max}}\right)$ of the airfoil. If students do not select the proper range of angles they will have to revisit the lab and re-run the experiment to collect sufficient data for comparisons with theory and published data, even though they may have a sufficient number of data points. This is definitely a good lesson in design of experiments.

Determine the appropriate number of data points – The number of data points needed for each type of measurement depends on the kind of relationship between the variables involved. For example, to capture the slope in the linear portion of the lift curve two points may suffice and a third one may be taken to confirm the linear shape. To accurately capture the airfoil drag bucket, however, students need to select more points. Again, the choice is left to the students, so they can develop appropriate judgment when they design experiments.

Obviously, students need to design their experiments very carefully, otherwise, they will not have enough data points and/or the right kind of data to make comparisons with theory and published data. An easy solution, of course, would be to prescribe all the information in steps 1 through 7 by providing a 'cookbook' lab but in doing so, we would be depriving students of the opportunity to learn how to design experiments.

The example presented above is a student-directed lab. Student-designed labs are more common in senior design and graduate courses. A reasonable question to ask at this point is whether we should eliminate completely all structured (cookbook) experiments from every laboratory. The answer is probably no, as these experiments help students develop more basic skills, which form the basis for more complex experiments. However, the design of experiments, like any high-level skill, requires multiple opportunities for practice and coaching in a variety of laboratory settings. Perhaps a reasonable approach to this dilemma is to offer structured experiments in the basic sciences (e.g. physics, chemistry, etc.) and expect students to direct and/or design all their experiments in upper division engineering courses. Thus, freshmen and sophomores with little laboratory experience will have an opportunity to develop basic skills in conducting experiments, analyzing data, and discussing results. Then, in junior and senior level courses, the bar can be raised and students should be expected to direct and/or design each and every experiment they perform.

Table 7.1 – The Inquiry Continuum

	COOKBOOK LAB	STRUCTURED LAB	STUDENT-DIRECTED LAB	STUDENT-DESIGNED LAB
Who? Design + conduct experiment; collect + analyze + interpret data	Professor designs the experiment.Students confirm a known result.	Professor designs the experiment;Students reach their own conclusion based on evidence.	Professor selects the topic;Students design the experiment.	Students select the topic + design the experiment.
Select Topic / Concept	Professor	Professor	Professor	Student
Pose Questions (Define Objectives of Experiment)	Professor	Professor	Student	Student
Select Materials / Equipment	Professor	Professor	Student	Student
Design Procedure	Professor	Professor	Student	Student
Collect Data	Student	Student	Student	Student
Analyze Data	Student	Student	Student	Student
Draw Conclusions	Professor	Student	Student	Student
Student Skills	Follow directions + familiarize with lab equipment + collect data + analyze data.	Skills in Cookbook Lab + make inferences +draw conclusions from a set of data +replicate results.	Skills in Structured Lab + pose the right questions +develop own procedures.	Complete design of experiment
Cons	Outcome is known; little critical thinking. Does not model true engineering process.	Students not involved in design of experiments.	Additional time to conduct experiments + additional materials.	Additional time to guide students + additional materials & equipment.

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