Chapter 2

So, what exactly does it take for your students to learn something new?

Chapter Objectives

A. Identify eight conditions, which must be satisfied to acquire a new skill.
B. Identify ways to satisfy these conditions in STEM education settings.

2.1 Background

The question on the title of this chapter was answered in the early nineties by Cambourne, a professor of education. In his effort to find an educationally relevant theory of learning, Cambourne conducted research with young children for a period over twenty years, from the early 1970's through the 1990's. From this research, he concluded that for children to master a language, eight elements must be present. He called these elements ***Conditions of Learning*** (1988, 1995). Since the vast majority of the children in the world manage to master the oral part of their language by an early age – a stunning intellectual achievement – it is safe to assume that all eight conditions are easily satisfied in their natural environment. Though Cambourne focused his research on the learning of language it has been my thesis that his eight Conditions of Learning are universal and must be present for the learning of any skill or subject matter (Mourtos, 2003). In this chapter, these conditions are introduced in the context of learning engineering.

2.2 Immersion

It has come to my attention over the years that some of the better students in my aeronautical engineering classes have been students who:

- Already hold aerospace engineering-related jobs.
- Are pilots.
- Are radio-controlled model airplane buffs.
- Love airplanes and read extracurricular material about them.
- Have double majors in aerospace engineering and aviation.
- Participate in professional societies.
- Participate on their own in design-build-fly competitions.

These students, though not always more intellectually capable than the rest, seem to have better intuition in engineering matters. For example, they are more likely to know right away when an answer in a problem is way off the mark. They are able to relate concepts we study in class to something they have seen or experienced in the real world, often sharing their experiences to the benefit of the whole class. They have less of a hard time with open-ended problems and design. Over the years I couldn't help but asking why? Cambourne's theory gave me an answer.

Cambourne observed that from the moment of birth, young language learners are constantly bathed in oral language. Before babies are even aware of what is going on around them, they are being exposed to the sounds, rhythms and cadences of what they must ultimately learn. Parents, relatives and friends talk to them or are talking around them before the young learners have any concept of words. This observation led Cambourne to establish "immersion" as the first necessary condition for the learning of language.

Students who fall in one or more of the categories mentioned earlier, enjoy a higher level of immersion in their subject matter than their classmates. Because of their hobby, job, double major or other activities, they spend considerably more time thinking about the intricacies of aeronautical engineering. For example, students with double majors learn to approach each subject from different perspectives, something which in itself enhances learning. In aviation classes they learn how to troubleshoot and maintain airplanes. They learn how to take them apart and put them back together. In aeronautical engineering classes, on the other hand, they learn how to analyze the performance of airplanes and how to design them. Students with double majors are able to make connections between the two worlds - maintenance on one hand and analysis/design on the other - and draw upon countless images from their experience in the former to help them with the latter. The rest of the students often struggle to visualize the various components of an airplane, which most of them have never seen before, while at the same time trying to understand the thermodynamic cycles of an engine, the compressible flow over a wing, or the rigid body dynamics of an airplane in flight.

Similarly, students who are pilots are truly immersed in aeronautical engineering in a unique and exciting way. For example, they practice stall recovery as part of their pilot training, so they understand aerodynamics better than anyone else. When we discuss boundary layers and flow separation they seem much more interested in the topic because they have vested interest in it; they want to know why, when they pitch the nose up the plane falls out of the sky. Occasionally, I have in my classes students who have flown commercial transports or fighters. These students can relate to flight mechanics in a unique way because they have experienced each topic of the subject in actual flight.

But flying real airplanes can be expensive, so many more students have been drawn into aerospace engineering through flying of radio-controlled model airplanes. These students can size the tail of an airplane using their intuition and experience with numerous models, while other students perform this task for the first time as seniors in an aircraft design class.

Finally, for students who hold engineering-related jobs, the day-to-day exposure to the real world of engineering, helps them make better sense out of what they learn in their classes.

In summary, immersion can be viewed as any exposure to the subject of study above and beyond the classroom walls. The longer and more relevant this exposure is, the better the results for the learner. The anecdotal evidence discussed earlier shows that this exposure (immersion) seems to improve academic performance and helps tremendously with the development of engineering intuition and skills.

Unfortunately, a large number of engineering students on many campuses spend a good portion of their time working on jobs which have very little to do with engineering. A reasonable question to ask at this point is whether there is anything we can do to increase the level of immersion of our students. Some ideas are offered below.

A. Pick up hobbies that relate to their major. For example, one of the best investments towards gaining a better understanding of aircraft design, is to get a pilot's license or learn to fly radio-controlled airplanes. The experience of flying an airplane goes a long way towards appreciating aerodynamics, propulsion, structures, controls, and other related fields. On a different note, it is also a matter of practicality and integrity; we would probably never buy a car designed by someone who does not know how to drive. Using the same standards, engineers who want to design airplanes should, at some point, learn how to fly. Similar hobbies can easily be explored for other engineering disciplines.

B. Visit interesting engineering sites. Seeing the actual objects of their study out in the real world is not only educating, it can be inspiring for many students. A field trip is a wonderful substitute for a class meeting. If you are going to introduce the structural design of bridges in your class, there is no better way to start than a bridge nearby, so students can see the various parts of the structure, touch the materials used, while you explain the reasons behind the particular design. Subsequent class meetings, which will deal with the mathematical details of the structural design, will be much more meaningful to the students. But for students to be truly immersed the occasional field trip with the whole class is not enough; they should be encouraged to visit engineering sites on their own as often as possible to broaden their perspective on things they learn in school. Excellent places for these visits include museums of science and technology, construction sites, local industry, etc.

C. Decorate laboratories and classrooms with pictures and models of state-of-the-art engineering products. This is perhaps the easiest way to visually immerse students and provide them with images from their field of study. A classic example of visual immersion, which paid high dividends in the end, is that of the Douglas engineers who created the DC-3, back in 1933. The Boeing company had just created the Boeing 247, the first modern airliner which replaced the Curtiss T-32 Condor, a second generation biplane transport. United Airlines, to which the 247 was first delivered, was threatening to leapfrog all of its competitors. Boeing at first refused to commit any of its 247's to any other airline except to United, so Transcontinental and Western Air (the predecessor of TWA) contracted with Douglas Aircraft Company for a better airplane. The story has it that the Douglas management put a massive picture of the 247 on the wall of their design room with these words underneath: *"Like this, only better!"*. The Douglas engineers did just that. They created the DC-3, one of the best airplanes ever built. As a matter of fact, the DC-3 surpassed in performance the Boeing 247 to the point that the 247 production stopped at 75 airplanes, while 13,154 DC-3's (including its derivatives) were built in the US, Soviet Union, and Japan. The Douglas management visually immersed their engineers into their challenge, until finally, the engineers were able to surpass it.

D. Coops, internships and summer jobs in engineering fields. Working in industry, even for short periods of time, is an excellent way to make connections between theory and practice. It gives students opportunities to see where and how, what they learn in the classroom, applies to the real world. But above all, it increases the immersion of the student in their field of study, simply by being there.

D. New technologies make it easier than ever before to increase one's level of immersion in any field, whether it is engineering or dancing. Furthermore, our students' natural ability to learn and use these technologies make this a very attractive option. I was reminded about this while I was explaining in my compressible flow class the other day the concept of an over-expanded and under-expanded supersonic nozzles. A student came up to me with his laptop and showed me a video of the Space Shuttle lifting off, clearly showing the at the exhaust the wave pattern associated with an over-expanded nozzle. It dawned on me that students can now immerse themselves in their field of study using easily accessible multimedia from anyplace, anytime.

2.2 Demonstration

All learning begins with opportunity and ability to observe, see, hear, witness, experience, feel, study, and explore some action or artifact. Young learners receive countless demonstrations of oral language. According to Cambourne, however, there is a key element, which makes these demonstrations effective. They are almost always ***'whole' demonstrations***. For example, when parents speak to their infants or toddlers, they use whole sentences with a specific purpose in mind. Thus, the demonstration provides enough information about the various systems and subsystems of the language, so that the learner will eventually be able to work out how all the pieces fit together and interact with each other. On the contrary, demonstrations that emphasize only one or two of the subsystems of the language, and de-emphasize or ignore others which typically accompany them, make learning less comprehensible and more complex.

Unfortunately, demonstrations in engineering courses can be quite different. Take for example the case of problem solving, which represents one of the most important aspects of engineering education. In many engineering courses it common practice to spend entire lectures with derivations and discussions on theory with no applications in sight. To make things worse, it was not until recently that most engineering textbooks started to include worked out problems systematically in every chapter. Even so, many students still complain that textbooks do not have enough example problems in many engineering subjects.

But the inadequacy of demonstrations in engineering education is not confined to the number of example problems that students see in each subject. When demonstrations are performed, what is often neglected is the importance of the 'wholeness' of the demonstration. Information in many cases is cut into pieces and spoon-fed to the students. While this practice may be necessary at times, whole demonstrations are essential for students to witness, and it is even more critical for those who are global and sensing learners (Felder & Silverman, 1988). Just like in the case of language, a 'whole' demonstration in engineering would provide enough information about the various systems and subsystems so that the student will have the data available for working out how all the pieces fit together and interact with each other. This principle is especially important in engineering design.

Case studies in design offer excellent opportunities for 'whole' demonstrations. In aircraft design for example, many instructors walk their students through the configuration of a particular airplane discussing the various decisions/choices the designer had to make. This process performs wonders for helping students see the connection between 'the looks' of an airplane and its mission specification.

But even when discussing very specific topics in highly specialized courses, it is possible to make a demonstration 'whole' by starting with an engineering artifact to provide appropriate context. For example, in aerodynamics we use boundary layer theory (Anderson, 2011, pp.965-1,030) to calculate skin-friction drag. Every text begins the presentation of this theory using the flow over a flat plate, to provide for the simplest possible geometry and mathematical analysis (Figure 2.1). This, of course, is quite appropriate. On the other hand, the example problems that follow tend to limit their demonstrations to flat plates only.

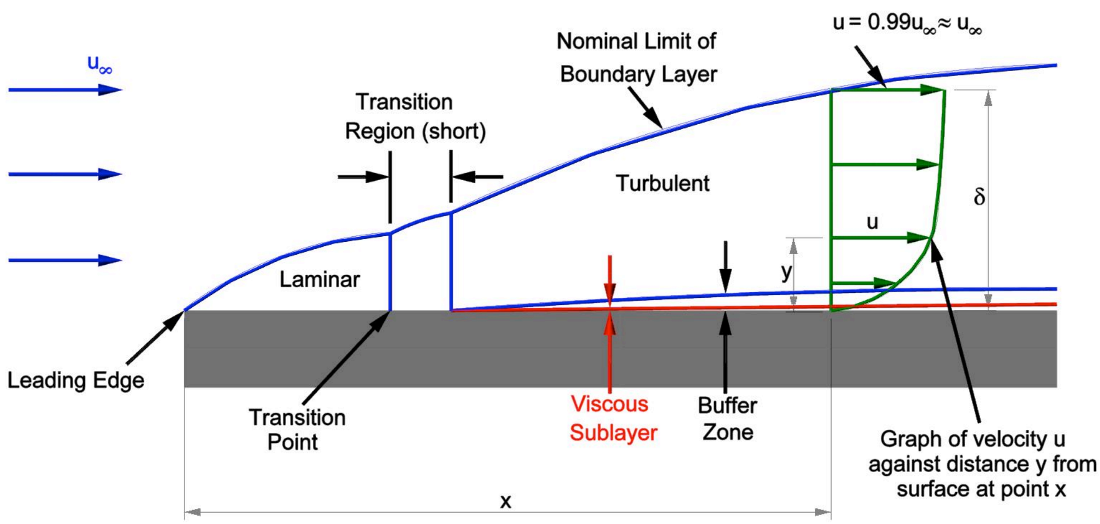

Figure 2.1 - A schematic of the boundary layer on a flat plate.

This approach is problematic not only because it lacks 'wholeness' but also because it misleads students to believe, that they can only use this theory on flat surfaces. This conceptual block prevents them from getting simple estimates of the skin friction drag of airplanes, automobiles, trains or boats, none of which looks even remotely like a flat plate. Yet, to a first approximation, aerodynamicists treat all these shapes as flat plates. A whole demonstration, would avoid this conceptual block by presenting the same analysis on an actual aerodynamic body (for example, the wing of the airplane in Figure 2.2). This approach accomplishes several things:

- It makes the demonstration more relevant.
- It gives the instructor an opportunity to explain, whether or not it is realistic to approximate the surface of the wing with a flat plate and how much of an error this approximation may introduce in the estimation of the skin friction drag.
- It offers an opportunity to extend the discussion to other aspects of this particular airplane design, as they relate to boundary layers. For example, the propellers were placed in the back of the wing to avoid disturbing the boundary layer on the wing. This is important

because the designer wanted to achieve the largest possible extent of laminar flow on the wing to minimize skin friction drag. The wing is unswept for the same reason. These details add flavor to the discussion and draw the interest of the students.

- The discussion can be extended to include other aspects of aerodynamic design. For example, the wing is placed way back in the fuselage to maintain standing room in the main cabin. This in turn places the fuselage too close to the horizontal stabilizer, decreasing its efficiency and necessitating the canard surface on the front of the fuselage.

Figure 2.2 – The wing of the Piaggio P-180 Avanti may be approximated as a flat plate to illustrate a simple application of boundary layer theory in the estimation of skin friction drag.

Seeing this airplane, students will usually ask questions related to other aspects of its design, such as stability and control or propulsion. This process makes it easier for them to make a connection with these topics later on in other classes. The important thing is that the aerodynamics piece of the puzzle is presented as part of a bigger picture and not as something isolated.

2.3 Engagement

While immersion and demonstration are necessary conditions for learning to occur, they are not in themselves sufficient. What may be missing from the learning equation is 'engagement'. Just like the engine of a car can be revved up unproductively without any movement of the vehicle, when the car is in neutral (i.e., the clutch is not engaged), so can students be immersed in their subject and exposed to many demonstrations without any learning taking place. So what does it take to get the students engaged? According to Cambourne:

A. Students must be convinced that they are potential 'doers' of the demonstrations. I have yet to meet parents, who conveyed to their children implicitly or explicitly the message that they may not be able to learn to talk. On the contrary, it is taken for granted that sooner or later their children will learn to talk and children tend to engage in the learning process because of this level of confidence expressed in them by their parents. Contrast this with the old practice of intimidating engineering freshmen in large auditoriums on their first day of class with comments like "look to your right, look to your left; only one of you will be here on commencement day". Not very encouraging comments, considering also that most freshmen are already quite nervous simply being there. Messages that explicitly or implicitly convey that what is about to be demonstrated is difficult and some of the students may not be able to perform it, will serve no other purpose but to discourage a large number of students, who would otherwise be eager to engage and have the potential to succeed.

B. Students must be convinced that by mastering the skills being demonstrated, they will improve the quality of their lives. A learner before engaging typically asks the questions: What's in it for me? Why should I learn this? An interesting illustration of this principle is the efficiency with which adult immigrants and their children learn the language of their new country. Granted that there may be other contributing factors, such as for example, difference in learning ability due to age, kids in general feel compelled to learn this new language, so they can ask for things and be able to communicate and play with their friends at school. Their parents on the other hand, may fulfill most or all of their basic needs using their native language at home, with friends, sometimes even at work. As a result, they do not always master the new language as quickly as their children.

The situation is very similar in the learning of engineering. Often students enroll in an engineering program for reasons that do not provide for strong engagement. For example, many think an engineering degree will help them find a well-paying job upon graduation. Is this a strong motivator to help students persevere through an engineering curriculum, especially when things get tough? As Csikszentmihaly (1990) found in his research with students of painting: "Painters must want to paint above all else. If the artist in front of the canvas begins to wonder how much he will sell it for, or what the critics will think of it, he won't be able to pursue original avenues. Creative achievements depend on single-minded immersion". Csikszentmihaly also found that it was those students who had savored the sheer joy of painting itself, who later became serious painters. Those who had been motivated in art school by dreams of fame and wealth for the most part drifted away from art after graduation.

Engineering is no different. Some students are extremely motivated and interested in their field. They have discovered engineering on their own, often through a hobby. There is no obstacle high enough to cause these students to drop out of engineering. The challenge, however, is to inspire, engage, and motivate the rest of the students who seem to be more ambivalent about their field of study.

Reminding students often and with specific examples, how much engineering has improved the quality of our lives, is one way to inspire them and engage them in our field. It took my uncle two weeks to reach New York from Athens by boat in 1950. I now travel from San Francisco to Athens in less than twelve hours every summer, in the comfort of a modern airliner. And while I am there, I communicate with my friends and colleagues in California, check my bank statements, and submit my papers to conferences around the world via the internet. We tend to take these things for granted, especially our students, who have never known a world without them but when we stop and think about it, they are all miracles of engineering, and students need to be reminded of this often, and encouraged to visualize themselves as creators of future miracles.

C. Students must be convinced that the risks involved, if they become engaged, both physical and emotional, are livable. Asking questions during class is one form of engagement. If a student asks a question, our response at the moment may have an impact on whether he/she will ask another question again. Obviously, our comments should be as positive and encouraging as possible. Any derogatory remarks on our part will only serve to discourage the student and his/her desire to ask questions in the future and be engaged during our lectures will be gone.

Cambourne adds, that the probability of engagement is increased dramatically, if the demonstrations are given by a person with whom the student has bonded. If students think highly of us and believe that we like them and care about them, they are much more likely to engage with our demonstrations. If, on the other hand, we are often grumpy, remote, sarcastic, threatening, punitive, and negative in general, it is natural to expect that students will be discouraged and lose desire to be engaged with our subject matter.

Brain research clearly supports these ideas. For example, it has been shown that our ability to learn has deep roots in relationships. Our learning performance may be deeply affected by the emotional environment in which learning takes place. Hence, the quality of education may in part depend on the relationship between student and teacher (Medina, 2008).

Unfortunately, educators face a big challenge today, as fewer students come to our institutions already engaged with their subject matter. One clear indication is that students no longer come to discuss assignments during office hours. The following statistics, presented by Mark Bauerlein (2015), an English professor at Emory University, paint a sobering picture:

- The percentage of frosh who declared as essential objective of their university education to *"develop a meaningful philosophy of life"* dropped from 86% in 1967 to 45% in 2015.
- On the other hand, the percentage of frosh, who declared as essential objective of their university education to *"become well off financially"* increased from 40% in 1967 to 82% in 2015.

2.4 Expectations

Learning a language is no easy task. Those of us who have tried to pick up a second language will agree that in most cases, there seem to be an extraordinary number of rules to master, not to mention that for each rule you usually find a good number of exceptions (whether we are talking about grammar or pronunciation). Nevertheless, and despite the difficulty of the task, children are expected to learn how to talk, and lo and behold, eventually they all do.

High expectations are often linked with excellence. Expectations can be communicated to students in a variety of ways. One way is the confidence we consistently display in their ability to be successful in whatever they are trying to accomplish. In spring of 1996 I came across the ultimate example of this truth. One of my aircraft design teams crashed their $1,500 radio-controlled airplane in their last test-flight, only three days before the Society of Automotive Engineers Aero Design West competition. The construction of the plane had been a major challenge all along. It had taken more than two hundred man-hours to complete, and there it was, lying in a corner of our laboratory in a form that resembled anything but an airplane. Panic and disappointment set in and the team leader wanted to quit and repeat the class the following year. After a good discussion with the group and their promise to reflect in writing on the accident I asked them what they wanted to do next. To my amazement, they decided to rebuild their plane, and get ready for the competition. Some thirty hours later I watched as my red-eyed, sleepless students were doing the final assembly of their "Phoenix", a name well deserved. What motivated these overworked students to excel to such a level? There may be many contributing factors but one of them is certainly the fact that I never allowed them to think of the possibility that their airplane may not fly.

Telling freshmen that they only have one-in-three chances to survive until graduation is one strong example of communicating negative expectations to the students. But it is possible to convey negative expectations in more subtle ways. As I handed out a computer assignment in my graduate aerodynamics class in the fall of 1995, I made the mistake of saying that it would be quite challenging to write those programs and get them to work. A couple of students were fired up with these comments, as they truly enjoyed the challenge. The rest of the class, on the other hand, interpreted my comments that this was going to be an impossible assignment and therefore, they should not waste any time on it. I did not realize this until several weeks later, as most teams had made no progress at all and I knew, that they had put very little effort into this project. It took a tremendous amount of rhetoric and encouragement on my part to reverse the original message and make the students believe that I was really expecting them to get those programs to run. My rhetoric was an attempt to convince them that these programs were relevant and worthwhile learning, valuable to their experience as aerodynamicists and would find them extremely useful when they start working in industry. Fortunately, my message was received by six out of seven teams. Two years later, one of the students from this class sent me an email from Cessna aircraft company, where he had found his dream job. He mentioned, among many things, that he was doing for Cessna the same kind of computational work that I had asked them to do on that particular assignment and he was very grateful that he knew how to do it. Never mind that the same student had confessed to me, shortly after finishing my course, that even though he was able to complete these computational assignments, he really had not enjoyed them as much as my lectures and class discussions on other, more conceptual topics. He had come full circle in realizing that sometimes it takes long, hard and tedious work to accomplish certain things in the engineering world.

The trick here is to convince our students that we are genuine about our expectations, our positive feelings and attitude towards them as well as towards our subject. But in order to be genuine about our expectations we must first get to know our students and their abilities. Goleman (1995) points out, that to achieve a state of 'flow' in learning, the activities must challenge the student to the fullest of his/her capacity. If the assigned task is too simple, it will be boring; if too challenging, the result will be anxiety rather than flow. Being enthusiastic and the degree to which we manage to make this enthusiasm contagious will also affect student attitudes towards our subject.

2.5 Responsibility

In every course I teach I include a weekly schedule, which includes, among other things, the topics I plan to discuss each week and the chapters from the textbook, which address these topics. Without failure, in every course I teach some students will approach me after class or send me an email requesting the exact page numbers in their textbooks that they should be studying the particular week. Obviously, these students are concerned that if they read the entire chapter, including a few sections, which we may not discuss in class, they will be wasting precious time! What is even more interesting, however, is that they don't realize they can get this information (i.e. the specific page numbers for a given topic) by consulting the index of their text.

To my delight, in every course I teach there are also students who approach me for information, additional references or even technical questions on projects, which I have not yet introduced in the course. Obviously, these students have studied the course syllabus, have made a plan on how to approach each topic, and they waste no time in getting a head start on their projects. These students illustrate beautifully what it means to take responsibility for one's own learning.

As we live in a world that is constantly changing, teaching students lifelong learning skills has become one of the hottest issues in educational circles. The first and most important step towards becoming a lifelong learner is, of course, taking responsibility for one's own learning. To accomplish this goal, students must be given opportunities on a regular basis, to make decisions about their learning.

In the case of young language learners, Cambourne observed that it is they who decide at which point in their lives, having been exposed to enough demonstrations of oral language from parents and others, will engage in simple conversations and start talking. Some of them start by using isolated words, while others wait longer until they feel comfortable using more complete sentences.

Although taking responsibility for one's own learning is and has been a necessary condition for any kind of learning, the level of responsibility that we allow our college students these days varies greatly from class to class and from culture to culture. It is my observation that in many cases, much of the responsibility, which by common understanding used to lie with the learner, has been transferred to the faculty, in an effort to make things "easier" for the students. This practice, however, can be detrimental to the development of lifelong learning skills.

There are many ways students may take more responsibility for their own learning, a few of which are highlighted below:

A. Take full responsibility for learning some of the material on their own. This responsibility includes studying certain concepts on their own, researching information, and even solving simple problems related to these concepts. Naturally, when giving students this kind of responsibility, it is best to start with topics that are fairly straight forward. Later on in the course of study, when students improve their skills in this area, they may be asked to pursue more complex topics on their own. Just like for any course material, students should be held accountable for meeting specific learning objectives related to these topics, through assignments and tests.

In addition to helping students develop lifelong learning skills, this approach offers other benefits, as well:

a. It frees additional class time for more challenging course topics.
b. It frees additional class time for problem solving and coaching students in higher order thinking skills.
c. It gives students an opportunity to acquire basic knowledge on topics, which normally would not be discussed in class.

B. Take responsibility to design their laboratory experiments.

C. Ask a team of students to present a new topic to the rest of the class.

D. Assign course projects and require students to come up with their own ideas about their projects.

In summary, this is one of the most important conditions for learning and one that requires a major culture change in academic circles, on the part of the faculty as well as on the part of the students.

2.6 Approximation

When toddlers learn to talk, Cambourne points out, they are always encouraged to try out new words or new expressions, and their attempts, no matter how imperfect, are always welcome. They are encouraged, in other words, to approximate what they are trying to imitate, and this approximation turns out to be an essential part of their learning process.

Approximations allow the learner to make mistakes in a controlled environment and learn from these mistakes. These approximations have always been important in engineering, which is why iteration is a standard procedure in any new design. Many inventions, which changed the course of our lives for ever, came after repeated failures. The epic story of the Wright brothers 'Flyer' is one such example (Moolman, 1980).

Yet, in our higher education circles, more often than not, we expect students to get things right the first time, whether it is a homework assignment, a lab report, a design project, or an exam problem. But this is impossible in any learning situation; we all know from personal experience that learning anything, from dancing to climbing mountains, involves a process of trial and error and progress occurs through repetition and refinement. Expecting students to get things right the first time stifles creativity, among other things, as it teaches students to stay within the framework of what they already know and avoid taking risks.

Allowing students to attempt problems during class (active learning) is one way to offer opportunities for them to approximate what is being taught. If this is done in small groups (cooperative learning), it also gives them a chance to see how others approximate the same concept. But even in formal assignments, such as homework problems or lab reports, I have found that learning is enhanced if students are allowed the opportunity to go back, given some feedback, and redo an assignment. Making corrections on a lab report and writing comments, gives the students valuable feedback. However, unless they are allowed, encouraged, and rewarded to go back and fix what they did wrong, there is no guarantee that they will ever learn what they did not know the first time.

2.7 Employment (Practice)

Students usually get many opportunities to apply what they learn in class, or so it seems. After all, what about all those homework problems, paper reviews, laboratory experiments, design projects, and all kinds of assignments invented just for this purpose?

While all of these assignments play a significant role in the learning process, sometimes there is a key element missing. Going back to the young learners of oral language, their opportunities for employing their newly acquired skills, always have some meaningful purpose for them. For example, they may ask for something they want or communicate with a friend to play a game. You will never hear a toddler practicing irregular verbs in the past tense.

On the other hand, mathematics, science, and engineering courses are full of drills. Drills may have the advantage of providing a simple place to start and to build confidence. On the other hand, they are by no means meaningful to the students. Let's consider a specific example from potential flow theory, which is used in aerodynamics (Anderson, 2011, pp.420-422) as well as in electrodynamics (Sommerfeld, 1952, pp.103-104). In aerodynamics, students are typically asked to calculate the induced velocity at some point in the flow field of a vortex using the Biot-Savart law (Figure 2.3). This exercise is a simple employment of this new concept, however, it lacks connection with the real world.

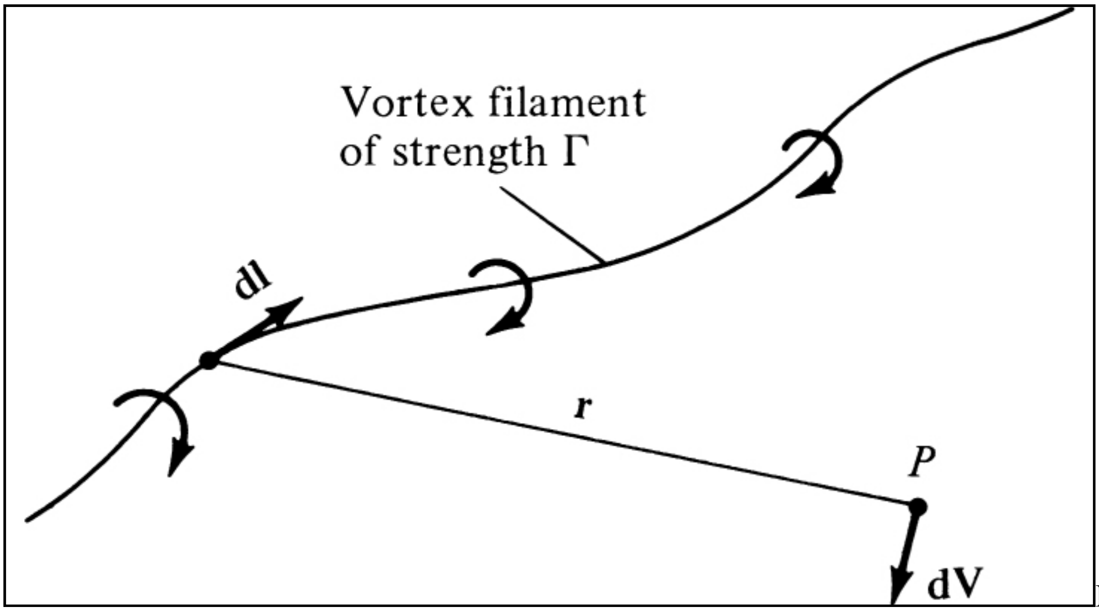

Figure *2.3 – An illustration of the Biot-Savart law in aerodynamics (flow velocity induced by vortex filament of strength Γ) or electrodynamics (magnetic field induced in a medium with permeability μ by an electric current of intensity I running through a wire).*

Aerodynamics:	*Electrodynamics*:
$d\vec{V} = \dfrac{\Gamma}{4\pi}\dfrac{d\vec{l} \times \vec{r}}{\lvert r\rvert^3}$	$d\vec{B} = \dfrac{\mu I}{4\pi}\dfrac{d\vec{l} \times \vec{r}}{\lvert r\rvert^3}$

Imagine instead, a Boeing 777 climbing out of San Francisco international airport (Figure 2.4) and a student pilot flying a smaller plane, such as a Cessna 172, caught in the wake of the 777. The students may be asked to ponder what will happen to the Cessna depending on its relative position with respect to the 747, and calculate its rate of descent (if caught in the downwash directly behind the wake of the 747), or its rate of roll (if caught behind one of the tip vortices of the 747). Figure 2.4 is a sketch of the related flow field.

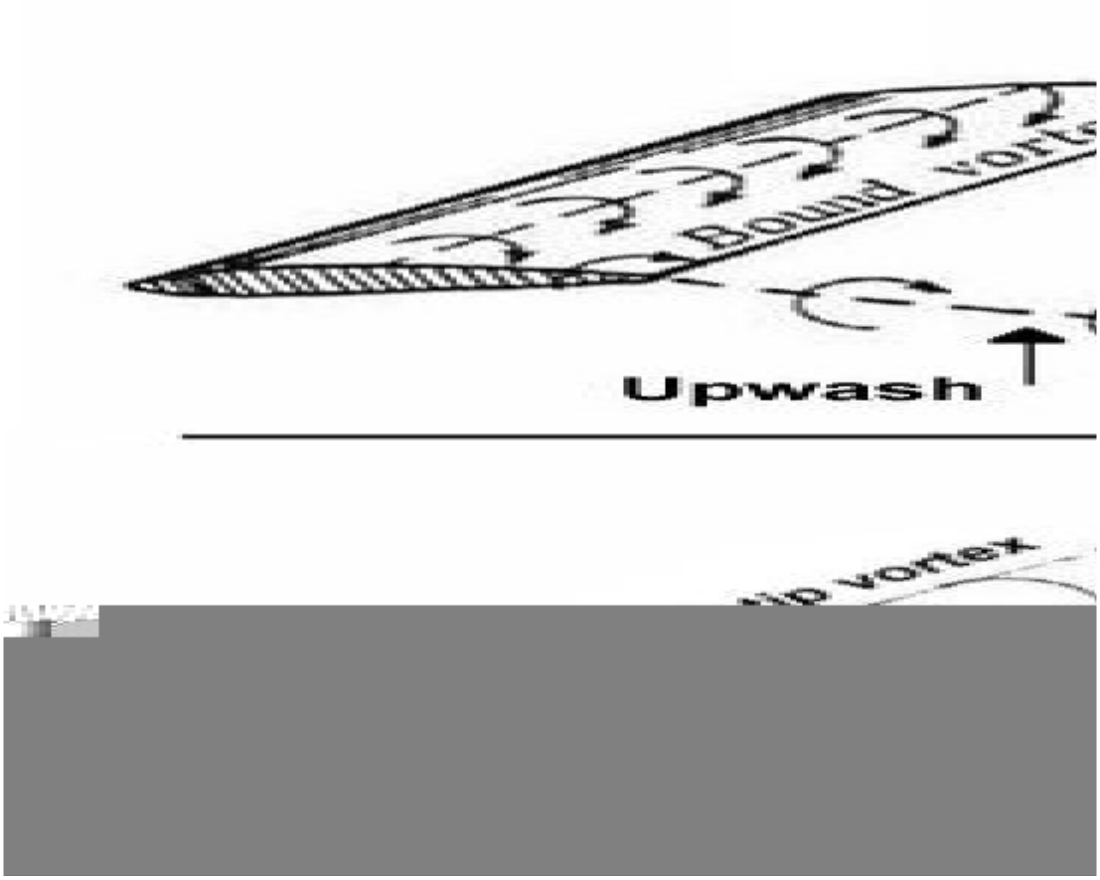

Figure 2.4 – An illustration of the flow field in the wake of a large airliner, as seen from the rear. The tip vortices induce downwash directly behind the plane and upwash in the regions outboards from each wingtip.

What is different about the second problem is its perceived importance to the students. The pilots in the class are eager to find out from the numbers, whether they have a chance of surviving such an incident. Students who fly often, want to know what is a safe distance for jet transports to follow each other on final approach. Thus, the perceived purpose for solving this problem is not to acquire some abstract skill but rather to answer their own curiosity about something important to them. In the process, of course, the skill of calculating induced velocities in the flow field of a vortex is acquired.

Another important aspect of employment is opportunities (or lack thereof) to employ concepts discussed in class to something in the students' personal lives. One of my students shared with me how after our class discussion on boundary layers (a fluid mechanics concept), she went home wondering why her homebuilt airplane was experiencing a pronounced nose-down pitching moment every time she encountered rain during flight. As she reflected upon this, she was able to apply what she had learned in class and come up with a reasonable explanation of what was happening to the flow over the wing of her airplane. Unsolicited opportunities of this kind to employ engineering concepts help reinforce the learning at a much deeper level.

To encourage this kind of employment, students may be asked to write a few pages of reflection at the end of a class session on what they think they learned, how they think the material applies to the real world, and in particular, how it relates to their own personal experience. This kind of reflective writing reveals a different level of understanding, which cannot be tested through problem solving. I am usually skeptical of students who manage to solve problems in homework assignments and/or tests, yet they cannot generate a few ideas in response to these questions.

2.8 Response (Feedback)

The term "response" is used by Cambourne as a synonym for feedback and it refers to exchanges between the learner and significant others for the purpose of sharing information about both the subject being learned, as well as the degree of control that the learner has over it, at any one time. Cambourne says that for feedback to be effective and contribute to the learning process it must be readily available and frequently given, timely, relevant and appropriate, and non-threatening, with no-strings attached.

Some of the traditional means for giving students feedback is corrected homework, design or laboratory reports and graded tests. However, in most cases, the feedback tends to be evaluative and no course of action is required for the particular assignment or test as a result of the feedback. Students need to receive feedback both formally and informally, from several 'significant others', on a much more frequent basis, so they can use it effectively to improve their approximations.

There are several ways to accomplish this level of continuous feedback in engineering classes. One-to-one discussions during office hours are good opportunities, provided that students take the time to come to our offices. On a daily basis, feedback may be given to students by their teammates (cooperative learning) as well as by the instructor, while they are working on problems in or outside of class. Coops offer yet another opportunity, as students who work on industry-sponsored projects interact with practicing engineers. Engineers from industry can also be invited to attend end-of-the-year student presentations and critique senior design projects. This kind of feedback is valuable for another reason. Students, especially seniors, are much more likely to take seriously any feedback offered by practicing engineers as opposed to feedback received by their instructors because of the familiarity developed over the years between students and their professors.

The combination of the last three conditions, employment opportunities, approximations on the part of the learner and frequent feedback, is an iterative process very important in the learning of engineering.

2.9 Conclusion

Cambourne's eight 'Conditions of Learning' are relevant and applicable in the learning of engineering. This makes sense because the cognitive process of learning does not distinguish one set of skills from another. These conditions are also in agreement with other research on undergraduate education, for example the Twelve Attributes of Good Practice (American Association of Higher Education, 1996). Thus, a good understanding of these conditions along with a conscious effort to meet them as best as we can in our course design, will result in enhanced student retention and learning.

References

American Association for Higher Education. (1996, April). What Research Says about Improving Undergraduate Education: Twelve Attributes of Good Practice, *AAHE Bulletin*.

Anderson, J. D. Jr. (2011). *Fundamentals of aerodynamics.* (5^{th} ed.). McGraw-Hill.

Bauerlein, M. (2015, May 10). What's the point of a professor? *The New York Times*.

Cambourne, B. (1988). *The whole story*, Ashton Scholastic.

Cambourne, B. (1995, November). Toward an educationally relevant theory of literacy learning: Twenty years of inquiry. *The Reading Teacher*, 49 (3).

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience.* Harper Collins Publishers: Harper Perennial.

Felder, R.M. & Silverman, L.K. (1988). Learning and teaching styles in engineering education. *Engineering Education*, 78 (3), 674-681.

Goleman, D. (1995). *Emotional Intelligence*, Random House Publishing: Bantam Books, p.93.

Medina, John. (2008). *Brain rules; 12 principles for surviving and thriving at work, home, and school.* (1^{st} ed.). Pear Press.

Moolman, V. (1980). *The road to Kitty Hawk.* Time-Life Books.

Mourtos, N.J. (2003). From learning to talk to learning engineering; Drawing connections across the disciplines. *World Transactions on Engineering & Technology Education*, 2(2), 195-204.

Sommerfeld, A. (1952). *Electrodynamics. Lectures on Theoretical Physics, vol. III.* Academic Press.