# Learning by Iteration: Evolving Capabilities in Aerospace Curricula

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**Abstract**

Electronic media allow engineering lectures to be covered in less than half the time it used to take. This paper explores the background and related issues, and argues for finishing the lecture material quickly, then using the time savings to revisit concepts, and integrate knowledge through several iterations. The experience from teaching five different courses at different levels is mined to gauge the lessons learned, and the improvements needed to use this new capability.

**Introduction**

This paper considers the opportunities opened by electronic presentation[1] of engineering course material. As course material gets completely converted, and classrooms become reliably equipped with electronic presentation facilities, instructors are finding significant changes. The time spent in drawing and writing on the board is saved, freeing the instructor to focus on the students. What was covered in a 75-minute lecture before, is now covered in 30.

A ‘safe’ option is to stretch out the lecture and add more examples and discussions. The down side is that many students are already put to sleep by the normal pace of lectures, which is set to accommodate the student needing the most time. Without the pressure of tests to intensely engage students, working more examples is generally a poor use of class time. Moreover, the really interesting possibilities are in putting everything together in realistic problems. This is best done with all the material already covered, but not at the end of the term when students face a steep rise in workload and pressure leaving little time for introspection.

The option proposed here is to finish the course material rapidly, and then revisit the content using integrative assignments. Dismissed as “drinking from a fire hose”, this is worth reconsidering given altered technology, expectations and learning styles. The questions are:

- Can students absorb the first exposure to concepts and methods, much faster than we had assumed in laying out courses?
- Is there merit in conveying the material quickly instead of taking twice as long to explain?
- Can the time savings enable knowledge integration and achieve a far greater depth of understanding and experience than was possible before?

These are fundamental to initiatives in improving engineering education, that run into the hard constraints on lecture time and credit hours for a degree. We are asked to include ever more topics, and teach them in ever less time. Can we reject a zero-sum game, and yet not dump information on students without enabling them to gain knowledge within the available time?

**Learning Through Iteration**

The idea that people learn better through several iterations is not new. However, applying this old idea within the constraints of an engineering curriculum remains difficult. The difficulty is in balancing the need for "training" with that for imparting new concepts in a fast-expanding field, within ever-tightening time constraints, to students who come in at the same age.

**Background**

The typical aerospace engineering curriculum of the 1970s through early 1980s required roughly 205 quarter-credit-hours (136 semester hours). Fluid / aerodynamics, structures, propulsion and performance were emphasized; aeroelasticity and design culminated the theoretical analysis and synthesis respectively. Given the paucity of computing resources in the undergraduate curriculum, we emphasized derivation of simplified analytical solutions, and extensive problem-solving using paper and pencil to assimilate analysis methods. Space studies were spread across departments of engineering science, mechanics, thermal sciences and physics. This fit well with the demands of graduate curricula and research programs.

Table 1 shows the compression in the fluid dynamics/ aerodynamics portion of the curriculum since the mid 1980s. The second column indicates the number of hours allotted to this subject area, with Q denoting Quarter and S Semester. Column 3 compares the number of equivalent semester hours. The last column is subjective, indicating the breadth of the content covered, relative to the situation in 1984. Computational techniques account for most of the new breadth.

Table 1: Time Compression in the Fluid Dynamics/Aerodynamics Curriculum

| Period | Credit hours (Q/S) | Eq. Sem Hrs | Breadth index |
|---|---|---|---|
| 1984 | 21 (Q) | 14 | 100 |
| 1988 | 14 (Q) | 9.3 | 110 |
| 2000 | 9 (S) | 9 | 115 |

Table 2 summarizes major developments that drove substantial changes. The early 1980s curriculum was considered to be too packed to contemplate large integrative assignments in undergraduate courses, and there was stubborn resistance from some faculty, passed on to students, against computer programming requirements. The ABET-approved U.S. aerospace engineering curriculum of the late 1970s lagged the best programs in India, for example, in the use of computers in undergraduate education. At the same time, U.S. programs were well ahead in dropping requirements[2],[3] for hands-on skills such as Workshop and Drafting. Early computer exercises in the late 1980s involved programming. As 'canned software' such as 'TKSOLVER' became popular, a debate arose about the value of having students spend time on programming versus solving engineering problems. The practice of coding entire, standalone programs including graphics from a blank sheet of paper, went into decline. Mathematical and graphical tools facilitated teaching computational techniques, flight control theory and computer-aided design. Addition of Space technology and design content further compressed the traditional areas.The broader fluids curriculum, with computational material added, now had to be taught in 9 vs. the original 14 semester hours. The availability of Internet resources, and the growth of electronic media brought many new tools and capabilities to the learner and the course designer.

More recently, the integration of Distance Learning into on-campus courses has driven the development of electronic material for many courses, and is causing a rethinking of the quality and opportunities of on-campus instruction.

Table 2: Major Developments Impacting the Curriculum

| Event | New Capabilities | Concerns |
|---|---|---|
| Advent of computer-aided problem-solving | Large realistic assignments | Time spent on programming vs. theory and "commonsense" problem solving |
| Canned tool vs. programming | Use in problem-solving; opened curricula in controls, simulation and computer-aided design | Decline of programming skills |
| Expansion of Sub-Disciplines | Broader curriculum; some cross-disciplinary problem-solving | Compression of the traditional subject areas |
| Internet usage in courses | "Virtual" office hours; broad-ranging sources; easy access to data. | Quality of content downloaded from the net vs. peer-reviewed materials. Decline in role of textbook reading. |
| Move into Distance Learning | Better standards of presentation materials driven by need to impress "real-world" students | Ability of students to learn and assimilate subjects without on-site eye contact with instructor |
| Electronic presentation formats | Rapid presentation of material; Superior eye contact with students; broad range of material included. Students learn to learn without copying everything from the board. | Instructor runs out of things to present, halfway into lecture. Concern about quality of assimilation of derivations and logic from electronic screen. |

**Progression towards iterative learning**

Table 3 summarizes progress that I have made towards enabling students to use iteration in learning engineering. In the early 1990s, dynamic digital imaging capabilities became accessible on personal computers, especially the Apple Macintosh, with reasonable levels of coding effort. By integrating these into course assignments[4], students could use images of real flows, conveying physical insight on dynamic phenomena. Laboratory experiments incorporated work with digital video. This found use in teaching static deflection modes, structural dynamics, and fluid dynamics. Solutions of differential equations could be linked to real flows and structures. Digital signal processing also became accessible on PCs, transferring experimental techniques from the research laboratories into the undergraduate curriculum. These capabilities enabled project-oriented courses where students learned theory and applied it immediately to projects.

We discovered that students could handle courses where several topics were learned in parallel, and where they created the "manuals" for their experiments. Project teams could interact through the computer. This was a far cry from the traditional model of undergraduates just being observers, or at best just operators following precise instructions.

The capabilities demonstrated by 1993 were used to revamp the junior-level Low Speed Aerodynamics course in 1994. This 3-quarter-hour course was under severe stress because curriculum compression had forced us to cover the equivalent of what was taught in 6 credit hours in the previous curriculum. The strategy adopted[5], was to reverse the order of presentation, and give the students a wing *design* assignment using a pre-written lifting line FORTRAN program early in the semester. Thus, by the time students reached Thin Airfoil Theory and Lifting Line wing theory, they were receptive to the theoretical basis of what they had been using for weeks. This showed the surprising benefits of integrating design early.

The above lessons about student learning capabilities, led to a bold experiment. We had developed an Introduction to Aerospace Engineering course, to be taught to first-semester freshmen to capture and retain their interest. Several ideas were tried in this course, with limited success. An overview taught through a large number of slides, left the students watching with interest, but not absorbing much. At the other extreme, some instructors tried teaching the conservation equations of fluid mechanics first. This was disastrous. Ultimately, I tried the idea of teaching conceptual design to freshmen[6]. Students were taken through the conceptual design of an airplane in eight weeks, spending 2 or 3 lectures on each topic such as aerodynamics and propulsion. This course required students to use individual initiative, and to explore far beyond their textbooks. It also induced students to work in teams of two each, on open-ended design assignments. With several senior instructors adapting this idea to their versions of the course, this has turned into a lasting success[7].

College freshmen at the end of the 1990s already knew how to find material on the web, and use email. This offered tremendous advantages in learning conceptual design. Where the student of the 1980s had to go to the library seeking one of the few copies of Jane's All the World's Aircraft in order to get benchmarking data, modern students obtain much more data in a few minutes on the internet, and thus develop their own empirical predictors for payload fraction etc. Fortuitously, the "scatter" in data from the Internet introduces students to dealing with uncertainty, and learning to decide what to believe, using their senses. This goes completely against the academic superstitions of depending only on the purity of "peer-reviewed publications", but tends to be more useful in the real world.

The experience with the Design-Centered Introduction validated the idea of a design-based portal to each discipline that could be fully understood and used by people with a high school diploma and background in any discipline. We used this idea to construct provided a web-based learning environment called "ADL" to help students and find in-depth content across courses[8].

By the early 2000s, we had fully integrated Internet capabilities into the aerospace curriculum. Web sites were in use for each class, students explored information from around the world in doing their assignments, and posted their own assignments on the Internet. Office hours of faculty were supplemented a great deal through email and discussion fora such as the "WebCT"[9] environment. Also around this time, Distance Learning technology moved from videotape to more web-based collaboration. The web-based discussion forum enabled students to work on teams regardless of geographical location. Initially, Distance Learning was operated through the Professional Education / Education Extension services, and hence there was considerable impetus to standardize the format of the material. This in turn induced us to convert course material into PowerPoint and web-based electronic media. Since classes were recorded before a "live" audience, the on-campus students also got experience in learning through electronic presentations, and were gradually weaned from having to copy everything down from the board. Instructors started running out of material to talk about, 30 minutes into a 75-minute lecture! The spiral had come fully around. Technology offered the possibility that the material we used to teach in a given course, could be taught in half the time, with no loss of comprehension.

Table 3: Progress towards incorporating iterative principles into the curriculum

| | | |
|---|---|---|
| Image and DSP-enabled PCs | Integrating experiments with theory | Physical insight, iteration |
| Multi-tasking in courses | Team projects | Learning new skills through iteration |
| Iterative Learning in a Theory Course | Re-ordered presentation to instill experience before theory. Showed how to fight compression | Showed value of design assignments in learning theoretical courses |
| **Design at an early stage** | Freshman introduction to aerospace engineering through a conceptual design sequence | Early perspective, freedom to exercise initiative in design, demonstration of learning across disciplines. |
| Fully Integrated Internet Capabilities | Freshman introduction used as portal to course material on several subjects | Vertical integration in a subject area. |
| Implications of Speedy Delivery of Lectures | Cover material quickly, and allow students to spend much more time revisiting the entire course | Convey the full range of course material quickly, without loss of assimilation. Second chance to improve assimilation by using the full range of the material in assignments |

**Implications of Speedy Delivery of Lectures**

Given that lectures were already converted to PowerPoint, and that students could not be forced to write down material that they already had printed out from the internet (or expected to, shortly), some use had to be found for the remaining lecture time. Expanding notes by adding new material, had limited utility. Structured problem-solving in-class was again of limited utility, because students need time to review and absorb material before participating meaningfully. In-class "discussions" would again be of limited utility, though all of these techniques are now used to some extent, given the large amount of "spare" time and energy.

I went another route: covering the material at the same pace, but finishing all the lectures (except for some "advanced topics") quickly. The remaining time was to be used after the students had seen all the course material, to provide an opportunity to revisit and use everything they had learned.

**Examples of Intensive Immersion Learning**

The first fear in instituting such intensive learning, rather than spreading the lectures out to fill all the hours, is that students will not be able to stay focused and assimilate so much in a short time. The counter is that even the standard chalkboard lectures do not really challenge students' thinking so much as their writing muscles. Are there examples where intensive immersion learning followed by practice, have worked successfully? I consider six examples below.

1. The Apprentice system in the West, and the ancient Gurukula system of education in India, mixed formal education with on-the-job experience under the guidance of an expert. This was "immersion" learning. The student was immersed full-time in an environment where s(he) was trying to learn as fast as s(he) could, in order to contribute to a fuller extent.

2. Modern medical schools impart a few subjects at a time, demanding full immersion for many hours a day in the application of the learning. One may argue that engineering requires deeper introspection to understand the complex theory, but this argument lacks conviction when one considers the complexity and extreme importance of what medical doctors must learn, especially where there is no opportunity for team members to catch and correct each other's errors in time. One finds oneself quickly backed into arguing that medical students are highly motivated and disciplined, and their selection process and expectations of work ethic are extreme. One looks elsewhere to rationalize a laid-back learning approach.

3. Closer to an engineering education, flight schools impart the education and training required to become a pilot, within a few weeks of very intensive learning[10]. There is no evidence that pilots trained in such an environment are any less safe than those who take a long time to train. Combat pilot training programs take this to extremes. Again, flight instruction is different from engineering education in that less of the theoretical background needs to be understood. However, there is a much greater demand for physical insight and lateral thinking in piloting than in engineering education, quite apart from the need to acquire a very good level of skill before one can expect to return alive from a solo flight[11]. The acquired bank of knowledge must be used in lateral thinking, literally "on the fly" and under many stressful conditions.

4. In modern software instruction, recognizes that beyond a basic education in the nature of computer organization and languages, professionals can "pick up" a new programming language and its nuances swiftly, though full immersion in using the technology on new projects[12].

5. Technology learning: One may targue that none of the above requires learners to get to the point where they are inventing new technology or methods (not that this argument stands up when discussing undergraduate education!) However, recent work[13] shows that the same techniques used in software instruction also carry over to learning many new technology areas, and to absorbing their fundamentals enough to carry out innovation!

6. Alumni of engineering programs in the mid-20th century report that the first half of the semester was devoted to learning theory, while the second half was devoted to intensive practice[14]. Given the above, one finds oneself out of excuses to not experiment with the potential of immersion learning in the engineering curriculum.

**Primers vs. depth, and Experience vs. Testing**

A strong caution against an “intensive” immersion program is that it may become just a primer, avoiding difficult steps. The counter is that much of the knowledge in textbooks goes unread by undergraduates today. So the reality may be that they don’t achieve depth or experience. A crucial difference enabled by the intensive immersion mode of teaching is that it emphasizes gaining experience much more than just “performing” on tests. The same time could arguably, be used in several in-class “quizzes”. In the present scheme, there is no need to reduce the amount of testing. In fact, we have the luxury of allowing students to be tested on the same material more than once, before the final exam, and hence allow them to assimilate the material much better.

**Courses Using Intensive Presentation**

1. Rocket Propulsion

I have tried the Immersion strategy in four recent courses. The first is graduate Rocket Propulsion[15], where I taught on-site and Distance Learning students. This course is not a core courses for the PhD qualifying exams, and hence the instructor has leeway in setting the syllabus. In converting from chalkboard notes to electronic, much material was added, conveying up-to-date information from research and development programs around the world. Still, there was plenty of time left over, and this was used to allow students more time to work on their large integrative assignments. The iteration here came through the opportunity to expand the assignments and midterm take-home projects into substantial semester-long integrative projects.

2. Junior-level High Speed Aerodynamics

AE3021 is a traditional junior/senior course, the last and most advanced in the fluid / aerodynamics curriculum. The theoretical methods that must be mastered make it a “hard” course. Here again, material was added, incorporating material provided by Boeing engineers on the High Speed Civil Transport aircraft. This material was at the professional level, and required students to integrate what they had learned throughout the curriculum in order to assimilate it. Again, students were doing the aerodynamic analysis of supersonic aircraft during the course, and this occupied their attention in the latter half of the semester. The opportunity for iteration was provided explicitly, in that two separate tests were given in the latter portion of the semester, on essentially the same material, with a 2-week interval of discussion and problem solving.

3. Design-Centered Introduction to Aerospace Engineering

I applied the intensive teaching scheme also to the freshmen Introduction to Aerospace Engineering course. Here, even more than in the junior course, I adjusted the pace of instruction carefully by observing the students’ attention and interest level. Again we could cover the material by the 12$^{th}$ week of the 15-week semester. The remaining time was used for integrative problem solving, as the students were putting their designs together at that time.

4. Intensive Workshop on Aircraft Design

An experiment was tried in December, at the Amrita Institute of Technology[16], one of the new private universities in Southern India. Faculty and students at all levels were invited to a 1.5 day intensive Workshop on Introduction to Aerospace Conceptual Design, essentially a compressed version of the freshman introduction course. The course was delivered in 6 hours of instruction on one day, and a 3-hour instruction and discussion session on the second day. During the first day, students were divided into teams of two, and they worked problems throughout, as each section was completed. The immersion exercise demanded intense attention and participation.

5. In graduate High Speed Aerodynamics, Spring 2006, new capabilities are used to vertically integrate undergraduate material, and reserve the latter half of the semester for projects .

**Discussion of Results**

The results to-date are mixed. In the Rocket propulsion course, the students performed extremely well, using the additional time to apply the material learned, without any apparent difficulties. Technology enabled us to bring relevant, state-of-the art information to the graduate student, without sacrificing the time needed to learn the theory in depth. Again, having the material available early, helped students to proceed to do very substantial and realistic assignments. Repeated comments from the Distance Learning students in several teachings of the course expressed pleasant surprise at the depth and relevance of the experience conveyed.

In the junior course, students did improve their understanding of the material substantially. The additional time for iteration did help. However, much remains to be improved in their will to learn from past mistakes and prepare better for tests. I discussed the test question which posed difficulties the first time around, but left its working to the students. Many were unable to get the problem right when it was asked again on the follow-up test, or on the Final exam two weeks later! This is symptomatic of deeper ills – a topic for a different discussion. In the Junior course we traditionally encounter many students who are in the deep valley of their college experience – they feel overworked, saturated with demands to learn mathematical theory, and lost in a mass of courses and technologies. The excitement of integration and synthesis that comes in the senior year along with the approaching end of their college days has not occurred yet. Thus it is crucial to set a large integrative project experience. This helps students to tie together all their newfound analytical tools, and see how they produce useful results. The new technological capabilities opened the way to do this, but further effort is needed to refine this capability.

In the freshman class, students were too new to college to adjust very well to the opportunities for iterative learning. Several students simply used the additional time to catch up on other courses where they were lagging, and skipped class. This negated the benefits of having additional discussion time. I considered a crackdown on attendance late in the semester, but dropped the idea as being of limited utility.

The immersion Workshop was a success in that students, mostly 3rd year Mechanical Engineering students, were clearly able to follow, and solve problems, and stay focused, through the 6-hour grind of the first day (the faculty were less able to keep up). Since the course was essentially completed that day, and they had stayed back specifically for this Workshop after their exams, most left for home right after the first day, so that attendance was sparse for the free discussion on the second day. However, feedback indicates that the students were greatly pleased with the intensive learning experience. The basic idea is to provide early perspective, engaging students in the detailed analysis that follows. Many students come with little or no exposure to engineering environments. The realities of the field are far different from the notions that triggered their interest. Thus in low speed aerodynamics, students need a physical understanding of how airplanes fly, before appreciating the need to calculate lift and drag precisely.

The Design-Centered Introduction was also set up with similar ideas in mind – provide freshmen an early experience of being aircraft designers. Again, this was seen to be crucial to get students to learn the different fields of aerospace engineering and get a useful overview.

The pedagogical basis for the Amrita Workshop experiment was the hypothesis that immersive learning would work quite well. Indeed, the students who took the course had had no prior exposure to aerospace engineering. Literally, starting at 9am with considerations of how much an average passenger might weigh, the students had reached the point by 3pm where they were calculating the range of a 100-passenger airliner. They did not reach the level of experience that would be reached with several weeks of struggling with a large design assignment. The perspective that they gained served as an eye-opener to what they could do in a day, and this was apparently an exhilarating experience.

Technology saves time in the instruction process. We have now come through enough turns of the spiral to be confident that there is no inherent dilution of rigor. Students can now discuss and understand many aspects of a design assignment early, in time for students to integrate them into their work. This solves one major problem in courses. Realization of how things fit together would otherwise come very late, or too late, in the course, preventing students from using that realization and thus cementing the concepts firmly. Did the students properly utilize these new features? As indicated above, results were mixed. Clearly, this was because the instructor did not quite know what to expect, and hence did not have the motivational tools ready to anticipate students' actions.

These experiments have some significant implications. They are sufficiently successful that there is no thought of going back – every course will have electronic course material. There is no hesitation to let students have these notes. At the same time, students must participate in class discussions, come better prepared, and solve problems inside the classroom. Thus the classroom environment can clearly become more interactive, with no loss of depth or breadth of instruction. The results are framed in terms of pedagogy concepts as outlined by Svinicki[17] in Table 4.

Table 4: Pedagogical Implications in the Framework of Ref. 17.

| Feature | Comments |
|---|---|
| Developing intellectual skills | Early perspective enables deeper questions and answers |
| Helping students understand and learn the content | Quick, focused lectures; greater emphasis on integrative assignments with plenty of problem-solving |
| Helping students retain and use what they have learned | Revisiting the same concepts and sections of the notes many times, in doing the assignments and preparing for tests |
| Helping students help themselves | Open-ended assignments, electronic notes |
| Motivating students to learn | Assignments are realistic and well-tied to practice |
| Accommodating individual differences in learning | Ability to present in-depth material, quickly to provide an overview, accommodates extremes of learner styles |
| Integrating knowledge | Plenty of opportunity and demand to use everything learned in doing the large integrative assignments |

## Conclusions

- A feedback loop has been established, between technology, pedagogy, course development, student learning habits, and instructors' understanding and initiative.
- Technology is used to free up time.
- Time is used to let students find and understand the motivation for learning the subject.
- Enhanced motivation and perspective enable students to face more challenging problems.
- To deal with these challenges, technology and motivation provide resources.
- Student attitudes and expectations change as a result of this experience.

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