Design-Centered Introduction: Experience with Iterative Learning

Narayanan Komerath
Professor, School of Aerospace Engineering
Georgia Institute of Technology

Abstract

Since 1997, freshmen at Georgia Tech have been introduced to aerospace engineering through the experience of conceptual design, applied to a complete aircraft. Lessons learned from the success of this ambitious experiment are examined here. The concept of iterative learning helps students maintain a high learning rate, and allows them to use what they learn, quickly. Support mechanisms for the first year are integrated into the course through various techniques such as the requirement to exchange knowledge and form teams. Through the initiative of several senior professors, an experience base has been developed, sufficient to enable students in Fall 2000 to design any one of several types of aircraft. Experience from this course is discussed, comparing various learning and motivating techniques with the expectations, capabilities and reactions of the students. In the first teaching of this course, it was verified that first year students already came prepared with skills and interests to excel in many aspects. Since then, teaching has been redirected to take the best advantage of these capabilities, and the results have been rewarding. The change in student attitudes developed through this course is becoming clear, as aspects which were tentative experiments to the freshmen of 1998 are now expected practice for the freshmen of 2000. The resulting potential for revolutionary changes to the curriculum is explored. It is implied that the curriculum can be restructured substantially, as students enter upper-level courses with an excellent experience base of doing the things needed to "gain perspective" on the field.

I. Introduction

Since 1997, freshmen at Georgia Tech have been introduced to aerospace engineering through the experience of conceptual design, applied to a complete aircraft. While such a project sounds ambitious for the freshman year, there are several reasons why it has become a successful experiment, with implications for the rest of the curriculum. Past ASEE papers described the basic concept of the Design-Centered Introduction course[1] and summarized teaching approaches taken by three different instructors in subsequent versions of the course[2]. In this paper, the concept of the Design-centered Introduction (DCI) is first summarized. The issues of learning by iteration are then examined. The two ideas are then related to each other.

Need for the course
Aerospace engineering attracts a large proportion of students who dream of designing and building new kinds of flight vehicles. In the curricular sequence which suits teaching based on deductive reasoning[3] Vehicle Design is the final course, reserved for the final year of college. Students entering engineering include many who are mostly inductive learners at the freshman level. They also lack the experience and perspective needed to apply what is learned in the deductive reasoning courses. Research[3] shows that the combination of these factors is a primary cause of frustration and poor performance in the first two years of engineering school.

Related Work
Several applications of design in freshman experiences have been reported prior to 1998[4-14]. Burton and White[14] report on a survey of models for teaching engineering design at the freshman level. Such courses were classified into: a.Reverse Engineering, b. Creating Something Useful, c. Full Scale Project, d. Small Scale Project, e. Case Studies, f. Competitions, g. Non-Profit Project, h. Redesign of a Local Project. Of these, they selected Reverse Engineering as most appropriate for their needs, using a Weighted Factor Scoring Model. Based on the experience of serving as academic advisor to over 1000 aerospace engineering undergraduates, I concluded that reverse engineering of specific devices or designs would be too narrow to cater to the diverse interests of the aerospace freshman class,

The choice of conceptual design as an integrative tool in our curriculum is based on the experience of listening to Georgia Tech Aerospace Engineering students and alumni for many years. In the traditional curriculum, the Capstone Design course in the senior year is cited by students for providing perspective on the various disciplines of aerospace engineering. The first six weeks of the 2-course Capstone Design sequence are spent on conceptual design. Hence it was argued that covering some of these concepts in the first year would have a dual benefit. The students would obtain perspective early, and the Capstone Design Professor could move quickly to more advanced topics. This would enable a large improvement in the scope of the senior Design course. A third benefit is expected to arise as other instructors begin to realize that their students have good perspective on the field: cross-disciplinary projects would become feasible, enabling an iterative revamping of the entire curriculum.

DCI Approach
We hypothesized further that the introduction of the Conceptual Design portion of this course, at the entering freshman level, would be highly motivating to the student. The steep learning curve needed to do such a design with understanding and confidence was weighed against the advantages of a motivated class. In 10-week Fall Quarter of 1997, such a course was first taught to a section of the freshman class. The course followed the traditional lecture –assignment –test format, but the initial lectures and assignments were developed to convey a sense of the process used to design flight vehicles. The remaining lectures were sequenced and developed such that students could build on their assignments into a conceptual design. The concept of a "runway across disciplines" (Figure 1) was used to take the students along a path focused on the design process. Steps in the design process are laid out in Table 1, and related to the various disciplines of aerospace engineering. This Table is given to the student at the beginning of the course. The detailed process of teaching the design-centered introduction is summarized elsewhere[1].

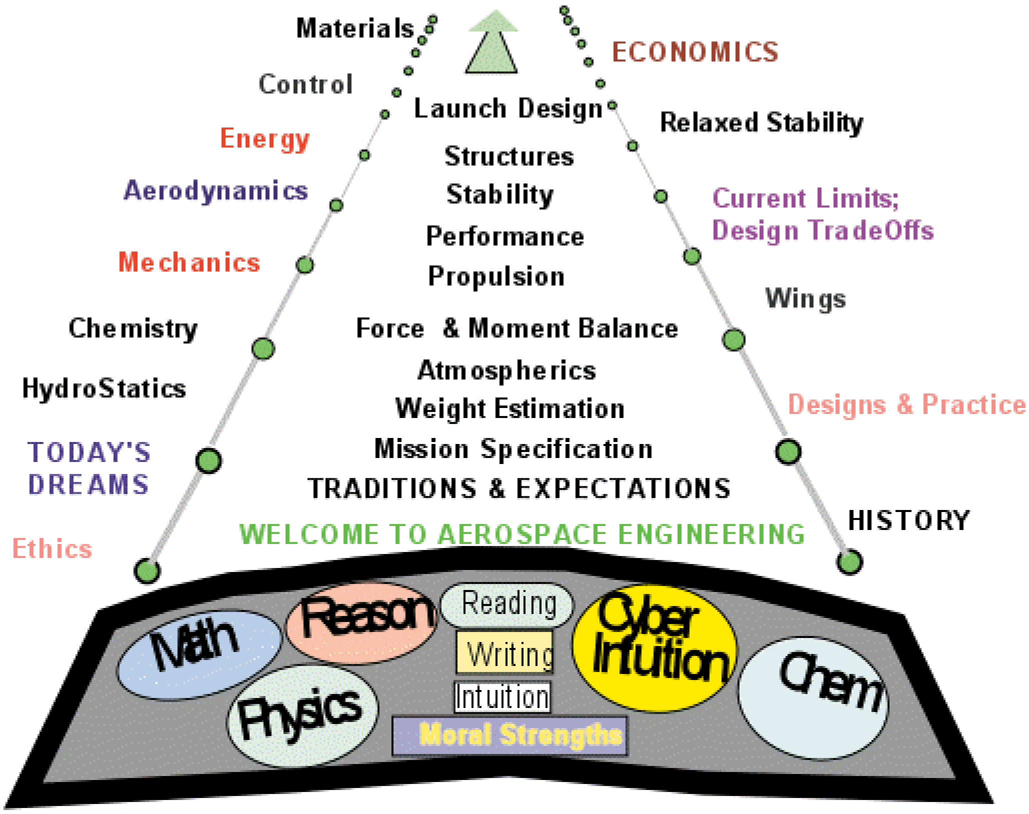

Figure 1: Conceptual layout of the Design-Centered Introduction (DCI) Course[1].

Table 1: Simplified Design sequence

Step	Issues
Define the mission	What must the vehicle do?
Survey past designs	What has been shown to be possible? (don't worry about WHY yet)
Weight estimation	How much will it weigh, approximately?
Aerodynamics	Wing size, speed, altitude, drag
Propulsion and engine selection	How much thrust or power is needed? How many engines? How heavy? How much fuel will they consume?
Performance	Fuel weight, take off distance, speed/altitude boundaries
Configuration	How should it look? Designer's decisions needed!
Stability & Control	Locate & size the tail, flaps, elevators, ailerons etc. Fuel distribution.
Structure	Strength of each part, material, weight reduction, life prediction.
Manufacturing:	Design each part, see how everything fits, and plan how to build and maintain the vehicle. Break down into manufacturing steps.
Life-cycle cost	Minimize cost of owning the vehicle over its entire lifetime.
Iteration	Are all the assumptions satisfied? Refine the weight and the design.
Flight Simulation	Describe the vehicle using mathematics. Check the "flight envelope".
Testing	Build models and measure their characteristics, verifying the predictions. Explore uncertain regions. Build & test first prototype.
Iteration and refinement	Keep improving, reducing cost and complexity, and extending performance, safety and reliability.

II. Iterative Learning

People learn better when they can apply concepts repeatedly to various situations. Parts of this concept are variously called “on-the-job learning”, “experiential learning”, “sensory learning”, “global learning”, “tacit knowledge”, “knowledge integration” and “practical sense”. Engineering curricula are designed to progress in deductive logical sequence to make the best use of the available time to impart knowledge. In this process, mastery at each step is hoped-for, if not assumed, before the next step is taught. To gauge mastery, grades are assigned to students on their level of mastery of each step. Often there is little opportunity to revisit the concept: students often abandon those learning steps where they “performed poorly”.

If students could see errors, revisit concepts and correct their understanding of how to apply them, learning would be reinforced. This process occurs in a relatively informal way when new students join a research group, and come up to the leading edge of a technical field. In the case of new graduate students, it may be argued that their excellent undergraduate background enables them to grasp the research literature rapidly. However, experience at our laboratory has shown that such learning works very well with students at all levels, and indeed this agrees with the experience of most people who learn on the job.

The postulate used here is that such ***iterative learning can be incorporated into the traditional course sequence by thoughtful integration of technology and learner-centered tactics.*** In other words, *students can be afforded the opportunity to master subjects through iteration, without making drastic changes to the curricular structure*. This latter point is essential for practicality, if the idea is to be implemented in the near term.

The implementation of iterative learning has been developed through previous experiments [15,16].

- At first it was applied to develop courses on Flow Diagnostics and Flow Control[15] where the students mastered the ideas in the course by developing one experiment in each team, and then serving as the expert “assistants” for the other teams to use their experiment.
- Next, the idea was applied to a core junior-level course on aerodynamics[16], where an open-ended wing-design assignment using a computer code was given early in the course. As students gained experience and “practical sense” on the influence of various parameters in designing wings, their motivation level and receptiveness improved hugely in the latter parts of the course where the theory needed to understand the analysis methods was presented.

Both of these experiments showed exciting prospects for breaking through some of the most difficult issues which we face as teachers and curriculum developers. Lessons from both of these experiments were used in bringing Iterative Learning into the Design-Centered Introduction course.

III. Application of Iterative Learning in the DCI

a) Overcoming obstacles to comprehension

The various factors inhibiting a freshman from carrying out a conceptual design project are summarized in Table 2. These are summarized from more than 200 e-mail messages received from students during the course, from midterm course evaluation comments, and from hundreds of individual discussions with students.

Table 2: Obstacles encountered by first-year students in performing a conceptual design project

Number	Description
2.1	Inadequate experience
2.2	Fear that other students have vastly greater experience
2.3	Absence of calculus background
2.4	Lack of experience in applying physics to problem-solving

Although the course designer may feel that the knowledge needed to succeed in the course is well within high –school syllabi, Items 2.2 and 2.4 prevent many students from performing to their full potential in the first attempt to do assignments. The solution is in Iterative Learning, where students are given the opportunity to revisit concepts and methods multiple times. The process of designing a flight vehicle is naturally iterative. The use of Design as an introductory tool offers strong advantages to the learner. As a part of the design process, the learner revisits the theoretical concepts and their manner of application many times while converging to a design which meets all requirements. An example of this process is shown below.

Concept:
Lift acting on an aircraft $= 0.5*\rho*U^2SC_L$

where
ρ is density
U is flight speed
S is the planform area of the lifting surfaces
C_L is the lift coefficient.

When students try to use the above expression, they encounter several problems, tabulated below

Table 3: Sources of confusion and error in learning to calculate lift.

Concept	Confusion / sources of error	Learning Methods
Density	1. Units in SI and British 2. Confusion between weight and mass 3. Missed exponent in atmosphere table leads to errors by orders of magnitude.	a. Worked examples b. Assignment c. Tests d. Design requires matching results to “typical”values from the literature
Flight speed	Units in SI and British	
S	Units	
C_L	Order of magnitude	

In the simple instance above, methods (a-c) are the conventional ways of reinforcing the concept, and performance on these indicators is quite satisfactory. However, when students actually apply the concept to the design problem, several of them make the errors indicated above. The design assignment requires them to resolve all of these sources of confusion, and hence enhances learning by a large amount. When it is recognized that the students will learn the concept thoroughly in the design process, it is not necessary to assign large credit penalties for errors in the initial encounters with the concept. The student leaves at the end of the course with the concept understood and reinforced through experience. In the absence of such opportunities, the same student might have left the course concluding that aerodynamics was a horrible subject, to be avoided in future.

b) Learning from Past Offerings of the Course

In the first teaching of the Design-Centered Introduction course, all students were asked to do the design of the same class of aircraft: a 400-passenger airliner with a range of 10,000 miles. Since then, the design assignment has evolved as shown in Table 3 (from Ref. 10), as different instructors tried different types of aircraft, with altered emphasis on the issues to be addressed in the design process. Student demand for the freedom to pursue their own interests drives the expansion of alternative designs.

Table 4: Aircraft conceptual design assignments[2].

Instructor	*Term*	*Type of aircraft*
Komerath	F97	400-seat, 10,000 mile airliner
Loewy	W 98	High subsonic executive jet transport.
Loewy	W 99	Long range, Mach 2 air superiority fighter
Sankar	Sp.99	Air superiority fighter
Komerath	Sp.99	300-seat hydrogen-powered airliner
Komerath	F 99	1. Light combat aircraft 2. Strike aircraft
Komerath	F00	1. Long-range general-aviation craft. 2. Hypersonic interceptor for ballistic-missile defense. 3. Supersonic Airliner 4. Supersonic business jet

c) Adjusting to College

One special feature of freshman classes is a large diversity in backgrounds and expectations of the students. In the first few weeks of the course, this diversity poses a strong challenge. The best solution, albeit a very expensive one, is for the instructor to provide individualized attention and guidance. For example, in the 1997 iteration of the course, the instructor confidently based the initial lectures on concepts using Newton's 1st and 2nd laws of motion. A student appeared in his office one morning, asking: "I have not had any Physics classes in high school. Should I drop this course?" Upon careful discussion, the student proved to have an excellent grasp of differential calculus, and readily understood the same material when explained in terms of vectors and temporal derivatives (and went on to excel in the course). A student in Fall 2000 started out with great difficulty in solving any algebraic equation at all, but again excelled once a helping hand was given to surmount the initial obstacles. One major problem is the feeling of many students that they are disadvantaged compared to students who arrive with Pilot's Licenses and technologically-advanced backgrounds. The opportunity for iteration is extremely important here. One idea which has worked well is to return the initial assignment in this course, with comments and grades of "A" or "incomplete", the latter requiring re-submission of the assignment. This overcomes the tendency of some students to give up early and settle for mediocre performance.

d) Relevance of Teamwork to Iterative Learning

After all students have done individual assignments, and at least one test, they are asked to form teams of 2 students each for the rest of the Design Assignment. In the latest offering of the course this posed more difficulties because students had to find partners who wanted to design the same kind of aircraft. The teams provided students with an opportunity to refine their understanding of the subject by comparing calculations and decisions with partners. An end-of-course survey expressed the near-unanimous agreement that the optimum size of a team at this level is indeed two. The survey also showed that these teams provided much mutual support in studying for tests, making web pages, and other aspects of college, since most students reported that they had not become acquainted with many other classmates.

Decisions and results from the design project were the topics of questions on a midterm test and the Final exam. These provided intermediate feedback as well as strong motivators of individual performance on the teams.

e) Role of the Internet in Iterative Learning

Over the years, the role of the internet has become stronger in learning. In this course, internet usage consists of the following:

- in the very first week of Fall 2000, students were asked to do Assignment 1 as an e-mail message to the instructor. This was to force students to set up their e-mail accounts, and overcome inhibitions about using the campus computer network, and e-mailing the instructor. Note that all students entering G.I.T. are required to own a computer, and the dormitory rooms have high speed internet access.
- In the second week, students were informed that they would be setting up their own web pages during the semester, and posting their assignments to those web pages.
- The course outline web page included students' e-mail addresses, mostly to encourage communication between classmates.
- Assignment #2 onwards required usage of the internet to find data on various aircraft for benchmarking purposes.
- All the notes for the course were posted on the Aerospace Digital Library, and survey comments show that this resource superseded the textbook as the main out-of-class reference source.

f) *Learning through the eyes and minds of classmates*

Perhaps the most important iterative-learning aspect of the Design-Centered Introduction is that students' expectations of themselves rise rapidly, as they see other students achieving at levels that seemed impossible a few weeks before. They realize that they have matured, themselves. *An anecdotal observation: In the first few weeks of the course, when the instructor had to leave the classroom for a few minutes to go get a replacement eraser, or something of the sort. As he* *returned to the classroom, there was near-total silence. When a similar event occurred in the last third of the semester, the animated chatter from the classroom could he heard from a long way down the corridor.* Question visits to the instructor's office in the final weeks of the course invariably turned into group discussions, with students from different teams commenting on how they solved the problems that others faced, and comparing notes.

The internet was used in this process as well. Many questions in this course come through e-mail to the instructor, usually sent in the evenings when the studying gets underway. Wherever appropriate, these questions were treated as questions asked in class, and the answers were copied to the whole class. Towards the end of the semester, a discussion forum was set up on the Aerospace Digital Library (see www.adl.gatech.edu) so that students could discuss issues in their design project; this was used less than the instructor hoped, for reasons not quite understood.

IV. Data on student perceptions of the course

Table 5 lists the methods used to document feedback on student perceptions and performance, to evolve the course. The techniques have evolved from the mostly "quantitative" assessments used by the Institute, to the free-form technical survey (FTS) used by the instructor in recent semesters. This FTS is most revealing of the students' thinking, and brings forth opinions at a remarkable level of thought and depth. Summaries extracted from the results are given below.

Table 5: List of assessment tools used in the Design-Centered Introduction course

Tool	Characteristics / purpose
End-of-course satisfaction survey by Institute's CETL	Uniform question set; quantitative; mainly about happiness with instruction
Mid-semester survey	Ditto
End-of-course ADL experience survey by Assessment office	Quantitative and free-form responses on experience of using ADL resources in the course
E-mail tracking	Informal collection by insructor to track evolution of each student's thinking
Cross-grading, Fall2000	Tracking reasons for errors on tests
End-of-course Free-Form Technical Survey by instructor, Fall2000	Not anonymous; permission sought for usage of opinions. Detailed answers possible

Qn: Before you took this course, what were your computer-skills? For instance, did you use e-mail before? Did you browse the web for any reason? Did you have your own web page? Did you encounter any problems because of any assumptions (apparently) made about your experience using the internet? If you did, what were they and who helped you to resolve them?
Responses:

Used e-mail: 13/16	Browsed web: 12/16	Made web pages: 2/16	Other students helped: 4/16

Qn. How much of your learning was from (a) the text book, (b) notes & discussion in class, (b) web-posted notes, (c) e-mail / office discussions with instructor and other students, (e) exploring on your own? Is this different from high school?

The nearly unanimous answer here was that the learning was 5% from the text, 60% from lectures/notes, 10-15% from web-posted resources, 10-15% from discussions and the rest from independent exploration.

Qn. How did your team project experience go? How did you organize meetings, share workload, communicate, and how did you help each other? How much help came from outside your own team? Do you prefer to work alone or in a group or 2? or larger groups? Do you now interact with classmates via e-mail or hallway discussions a lot more than at the beginning of the semester?

Students were unanimous about the value of teams, and that two was the correct size for the team to enable effective interaction. The team experience appears to have gone very well. Beyond the teammate, interactions with classmates appears to have been limited, though some cited making many friends through discussions of the design project. Though they had been encouraged to discuss the project with other teams, and a great deal of such assistance did occur, some students cited the uncertainty of "prying" into other teams' approaches.

Comments about Iterative Aspects
A few telling comments show how learning by iteration makes a large difference. These are extracted from answers to other questions: nothing was asked specifically about iteration.

Table 6: Comments about iterative aspects of learning used in the DCI

I used to prefer to work alone, but I am opening up to the fact that I cannot do everything myself. There are many ideas that would have stayed submerged without the two person interaction.
...And to be completely honest, I really thought this class was a waste of time for most of the semester. It is now that I realize how much I've learned about how an airplane works and I believe that doing the project was a fantastic idea. I am so much more happy that I am an AE major now.
The course web page was of great help throughout the course. I used it almost daily while doing the assignments and studying for tests.
I got onto the web page www.adl.gatech.edu at least 6-7 times a week. Other links through ADL? I travelled through most of the links on our course page.
I accessed the web page many times a week to read and re-read information to solve AE problems, and to work on the design project.
(used the web-based notes)..Very often, especially while working on the design project. It was a great help there.
I found it rather interesting to totally explore the ADL web site on the first visit. This became very helpful as I found it easier to understand the lectures.
The main difference from high school was that a lot of individual work outside of class was necessary for full understanding. In high school I could just listen and take notes in class and not have to study at home.

Change in Student Attitudes
The change in student attitudes developed through this course is becoming clear, as aspects which were tentative experiments to the freshmen of 1998 are now expected practice for the freshmen of 2000. Examples are:

In 1988, the students appeared to be very concerned about the idea of designing an entire aircraft. Colleagues and seniors had informed them that this had to be a crazy notion. However, the students worked very hard and succeeded. By the second and third time the course was taught, in 1999, students were informing the instructor that they wanted to do something more "original" than designing airplanes with conventional hydrocarbon fuels: by popular acclaim they decided to design hydrogen-powered airplanes, overriding the instructor's expressions of concern. The idea of doing conceptual design in the freshman class had become "routine". Web-based notes on the course were provided, but students were still unused to the idea of finding useful data through the internet, and several concerns were expressed regarding the instructor's expectation that they do so (example: "why are we spending all this time surfing the net?"). Students were still learning primarily from class notes and the textbook, though some were using the web-based notes effectively.

In the latest teaching of the course (Fall 2000) the instructor faced a larger problem: students demanded to be allowed to design their "own" planes, and were eventually persuaded, with some disappointments, to choose from 4 different classes of aircraft. Finding data on previous designs over the web had become routine. Making their own web pages and posting the designs there was not routine, but they did a good job of it eventually. The learning styles had changed (though students mostly denied feeling that they had changed) and now they are learning first from classes and class notes, secondly from web-based notes, and last from the textbook. Unlike this instructor's experience of most of the past 16 years, students are not commenting any more on the readability of the textbook in course evaluations, but instead focusing on how to get projects done, with the textbook viewed as one of several sources of knowledge. This is a far cry from 4 years ago.

The extensive usage of e-mail for out-of-class assistance and discussion is another major change. Rather than waste time waiting outside professor's offices, students feel free to e-mail their questions and comments as they study (7pm – 11pm). Though this sounds rough on the instructor's schedule, the reality is that these messages are a welcome break from writing papers and proposals (one usually knows the answers and can hence feel useful). Catching students while their brains are focused on the task is a great way to enhance learning. The expectation of e-mail accessibility, spread among friends, did get students in another section of the freshman course into difficulty, because the instructor in that section was not used to dealing with students via e-mail. This is another sign of how the students' expectations and learning styles are evolving, forcing instructors to change and catch up.

As the students from the first teaching of the Design-Centered Introduction reach their Senior Capstone Design, comments from the instructor there are beginning to reveal a substantial change: the instructor is being pulled along by students eager to move ahead with the design, faster than he wishes to move.

V. Implications

Three years ago we were analyzing the results from using a Design-Centered Introduction in the first term of college in Aerospace Engineering. Experience has shown that our first-year students are quite capable of delivering excellence in such a course, and understand many concepts and methods which we used to reserve for the junior and senior years. The course has been taught by several senior professors, who are unanimous in agreement that it works well.

Implications for curricular reform

To repeat from what was presented to the Design session at the last ASEE meeting[2]: "A deeper implication is that a total restructuring of the curriculum is possible, using the lessons learned about the capabilities of freshmen to comprehend and excel at design. We have shown that the simpler concepts of design can be learned very early in college, so that every succeeding experience can build on this foundation. Without this experience, students spend 3 years learning that rigorous, near-machine-like adherence to sequential processes is the life of the engineer. The excitement and freedom of judgement, decision-making and creative engineering come far too late in the curriculum. With a broad experience such as that described here, following teachers can ask students to range far outside the boundaries of each discipline-specific course, and solve grander problems which use knowledge from several disciplines. This would open the way to a true revolution in engineering education."

Importance of opportunities for iteration

The reason why the students are able to succeed so well in such a course, despite huge differences in their background entering college, is the opportunity for iterative learning. The ability to revisit concepts many times, both through the web-based resources and through the design experience, makes an enormous difference to their ability and confidence level in grasping concepts. The presence of the textbook, the lectures, the web-based resources and the design assignment, make a network of learning tools which meshes very well, enabling students to learn much better.

Evolution of student attitudes

Qualitative results indicate that students' attitudes towards the Design-Centered Introduction have rapidly changed, and the "crazy idea" of 3 years ago is now routine expectation. Students' learning styles and ability to use the internet effectively, are changing rapidly too. These changes are beginning to impact the pace and performance in the Senior Capstone Design course as well.

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VII. Biography

Dr. Narayanan Komerath, Professor in AE and director of the John J. Harper wind tunnel, leads the Georgia Tech Experimental Aerodynamics Group (EAG). He has taught over 1600 AEs in 19 courses in the past 15 years. He is a principal researcher in the Rotorcraft Center of Excellence at Georgia Tech since its inception in 1982. He is an Associate Fellow of AIAA. He has won GT awards for Outstanding Graduate Student Development, Outstanding PhD thesis advisor, and Most Valuable Professor (GTAE Class of '91). EAG research projects have enjoyed the participation of nearly 100 undergraduates over the past 14 years. EAG is a leader in multidisciplinary team-oriented projects, including the Aerospace Digital Library Project at Georgia Tech: http: //www.adl.gatech.edu