The Virtual Laboratory: Technology Enhancement for Engineering Education

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Abstract

This paper continues work on defining the proper role of technology in enhancing learning. This role also evolves as student/instructor characteristics and experience evolve. The first application addressed was that of augmenting traditional classroom lectures so that classroom and homework time becomes a laboratory of learning and reinforcement through iteration and application. This approach directly develops the engineering attributes set forth in ABET 2000 Criterion 3.. Several examples of the technology-based virtual laboratory are provided. Positive and negative factors from teacher and student viewpoints are discussed, and how students with different learning styles behave with respect to the new methodology introduced in these classes. Experience accumulated from several teachings of aerospace courses at all levels from freshman to graduate, and subjects ranging from the abstract to the hands-on, is discussed. The diversity of student reactions indicates the critical need to understand learner attributes in detail: the use of technology in this effort is shown. While the classes discussed herein are Aerospace Engineering classes, the techniques are applicable across any engineering discipline.

I. Introduction

Engineering educators contemplating the criteria of ABET2000 quickly realize that in the long term, these criteria cannot be met unless major changes are instituted in the way that the curriculum is structured, delivered, and learnt. The leading edge of each discipline moves away at ever-increasing speed; innovations cut across traditional discipline boundaries, constantly increasing the amount of material which must be included in the curriculum; and the time available to teach keeps decreasing. Meanwhile, there is pressure to use technology in improving education, and the general public expects engineering schools to stay at the leading edge in their usage of technology in the classroom. This is the environment which motivated the work reported in this paper.

Table 1: ABET2000 Criterion 3 – Program Outcomes and Assessment [Error! Bookmark not defined.**]**

ABET Outcome
An ability to • apply knowledge of math, science & engg • design & conduct experiments, analyze & interpret data • design a system, component, or process to meet desired needs • function on multi-disciplinary teams • identify, formulate & solve engg. problems

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• understand professional & ethical responsibility • communicate effectively
The broad education necessary to • understand the impact of engineering solutions in a global and societal context • a recognition of the need for, and an ability to engage in life-long learning • a knowledge of contemporary issues
Ability to use the techniques, skills, and modern tools necessary for engineering practice.

Table 1 lists some of the criteria in ABET 2000. The accreditation process also requires educators to develop appropriate assessment methods to determine if progress is being made towards appropriate goals. It is apparent that such methods must be a combination of qualitative and quantitative methods; their implementation is daunting in terms of the time and effort required. In order to achieve the ambitious goals of ABET 2000, it is imperative that each student learns to the best of their ability throughout their undergraduate experience. This is extremely difficult to achieve in traditional classroom settings when one recognizes that each individual student has a *combination* of the traits associated with different types of learners.

In this paper, we begin to examine how each of these issues fits into a technology-based approach towards the engineering curriculum. The paper begins with a discussion of the research literature on how engineering students learn, and what needs to be altered in the teaching/learning process. It then goes on to discuss how technology is being used in various courses at the School of Aerospace Engineering at Georgia Institute of Technology (GIT), to simultaneously enhance learning and address the issues presented above. Assessment methods developed in the course of this research are discussed. Student reactions gathered from these tools indicate the diversity predicted by the work on learning styles. Again the role of technology is examined in catering to the learning styles of individual students.

II. Past Work on Learning Styles

Felder and Silverman [1] cite the mismatch between learning and teaching styles commonly found in engineering school. Student learning styles encompass the spectrum of classifications, but faculty can typically teach to only a fraction of these learning styles within their constraints of time and resources. For example, Keri [2] reports that differences in learning styles of college students had a direct impact on their grades in a course, depending on the teaching style that was utilized. Students whose learning style was congruent with the teaching style typically earned higher grades.

Given curricular time constraints, it is vital to ensure that the time spent on learning be quality time; students must retain information to which they are exposed. Ref. [3] describes the time required to learn the material as being proportional to the amount of material to be learned. That is, while time-on-task is necessary for learning, it is not sufficient to guarantee learning. Several concepts must be addressed within this framework. Students in the classroom may range from being learning-oriented, and liking new challenges, to being performance-oriented and concerned mainly about mistakes and their impact on grades. Material must be presented in multiple

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contexts for clarity to ensure that students can retrieve information in non-context (near and far transfer) problems [4, 5].

Recent research [6, 7] has indicated that the development of "meta-courses" where supplementary material and activities are provided outside of the traditional classroom has yielded positive results in reaching students whose learning styles are not compatible with traditional classroom lectures. Technology provides the catalyst to not only provide this meta-course material to students, but also to encourage interaction with the professor and other students outside of the traditional classroom environment. Zhu [8], as well as our own experiences with web-based learning at GIT, have shown that thematic discussions based on weekly reading assignments promote both horizontal and vertical integration of material, which otherwise does not happen in the traditional classroom setting. It has been found that this method, in conjunction with classroom lectures which are regularly scheduled or scheduled as needed, promotes deeper understanding of complex material.

In ref. [9] we presented results from two different kinds of courses where we studied the application of technology to the teaching / learning process. The first was a senior Core course in *Vibration and Flutter* This course was modified to incorporate technology in a manner so that learning was reinforced by a number of methods. This course served as a good test case because it relies heavily on previous material in other courses, yet a portion of the material is new to the student, requiring derivations to understand the methodology. Two classes (Spring 1998 and Spring 1999) were used to provide feedback on the modified approach. Limited data from class 1 (Spring 1998) were used to develop a more comprehensive anonymous survey for class 2 (Spring 1999).

The approach taken in this class is depicted in Figure 1. Full-time lecturing was replaced by assigned pre-lecture reading and augmentation of notes through the Aerospace Digital Library (ADL).9 Instead, lectures were based on questions from the pre-assigned reading or explanations of traditionally difficult material. The time freed from lecturing was spent by giving demonstrations of current research related to the topic, problems that were worked in groups or interactively with the professor, or hands-on demonstrations. Traditional homework problems were augmented by writing & running codes relevant to specific problems, as well as a group project. The overall correlation of the student response appeared to be weighted (though not 100%) with respect to the student's experience in the Math prerequisite. If the student had a poor experience in the prerequisite, he/she was more likely to have a more negative perception of this class than students who had a positive experience in mathematics.

The second aspect of technology usage in courses is considered in the context of a course on Flow Diagnostics. In this course, students must learn a substantial amount of the theory, principles and analytical methods behind advanced diagnostic technique. Yet, in the space of an 8-week Quarter, teams of 2 students each, also have to set up, operate, and analyze one research-grade experiment, as well as use and understand the experiments developed by all the other teams in the class. Here, technology comes into play in all aspects, from finding information and knowledge across disciplines and levels, to conducting experiments, analyzing results, creating their own web resources to let others use their work, and reporting on the work in classroom presentations. The course is generally conducted in a multi-media-equipped classroom, where

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the students and instructor can access the internet, and project material onto screens. The speakers in the room are also used to demonstrate such things as changes in frequency of sound as a diagnostic of flow effects.

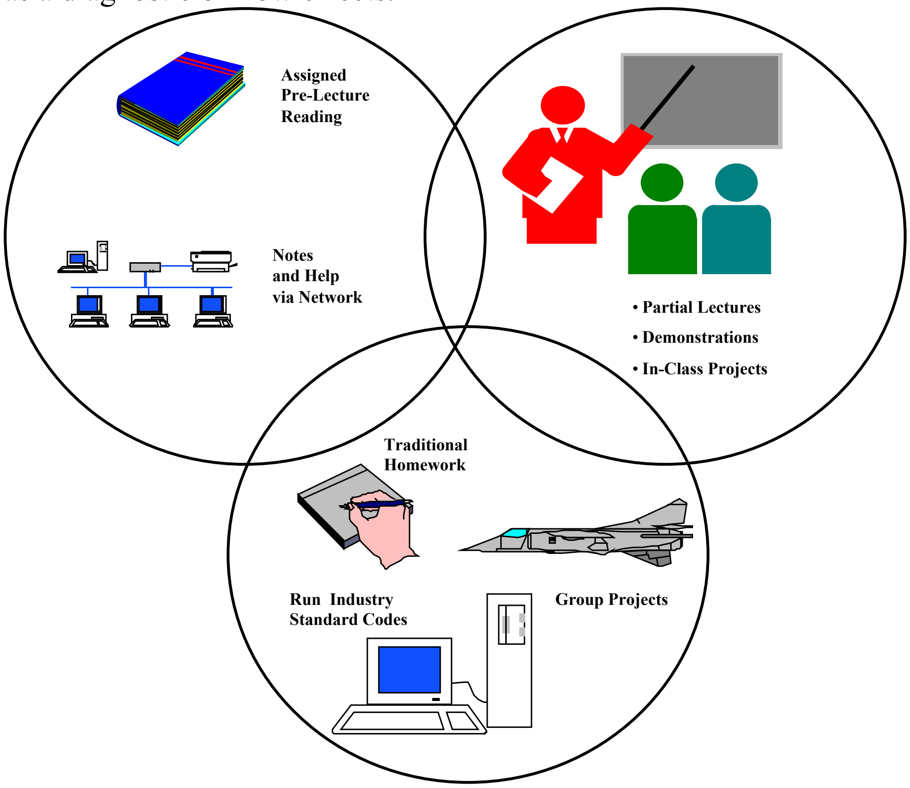

Figure 1: Augmentation of Classroom Experience Through Technology

The results from these experiences are summarized below. Classroom demonstrations using the computer or the internet are very well received, when the difficulty of the material merits a demonstration. Where students can be encouraged to help each other, with instructor observation, the results are even better, as the confidence level of the students rises dramatically in a short time. Group assignments using the internet as the forum are also very well received. The problem of "clearing" enough lecture time in order to permit these items can be met by requiring incremental reading assignments, but it is clear that the students need to be introduced to this concept at an early stage in their engineering education. Likewise, problems that require thinking or that have no definitive answer should be introduced earlier so that the students' thinking skills are honed prior to graduation.

In the required senior level course, it was apparent that although most students felt that they benefited from the experiential opportunities provided during class time, many were still very resistant to preparations outside of class (reading material that was previously class lectures). Because this method of teaching is different than the traditional methods utilized in other core courses, it appears that the Hawthorne effect is apparent when new methods are introduced at such an advanced level in the curriculum. It is noted that this effect was only obvious in the required course; student opinions on the elective course did not reflect the same attitudes. This

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may be because the elective class was taken only by students who were learning-oriented, as opposed to the required course, which contained both performance- and learning-oriented students.

In experimental courses, internet and multimedia technology become a natural asset in finding knowledge across disciplines and levels, as well as presenting experimental results. Technology facilitates group projects, enabling people with different schedules and other constraints to share information and work as effective teams.

From these classroom experiences, it is evident that technology can be utilized to enhance the classroom experience for the students, as well as to satisfy the new ABET 2000 outcome criteria. This experience need not be relegated only to the Capstone Senior Design classes, but with some thought can be incorporated into other classes as well. In our school, the process now begins with a Design-centered Introduction to Aerospace Engineering, where first-term students use technology to help learn across disciplines, and integrate their knowledge into a conceptual design in a team project [10].

III. Student Learning Methods and Applications of Technology to the Curriculum

The application of technology to the classroom is a topic of strong debate in our environment. Several levels are considered.

Table 2: Instructional Technology Usage Levels (ITUL) considered in teaching undergraduate and graduate courses in aerospace engineering

ITUL	Approach
1	Traditional classroom-chalkboard-lecture-homework-test system. Computer usage in assignments discouraged; hand-calculations and derivations emphasized
2	Assignments require computer usage
3	Transparencies replace chalkboard
4	Large assignments, integrated through the term using computer programs; software written by students. Computer usage integral to learning: numerics used to generate results for physical insight
5	Internet usage to locate and interpret knowledge resources.
6	Assignments via web-page
7	Document camera/ projector replaces transparencies to supplement chalkboard
8	Web-based notes in pdf form replace hardcopy monographs
9	Web-based notes in html with interlinked resources, external and internal
10	Remote instruction / talking-head
11	Multimedia for physical insight from experimental results and numerical simulations
12	Multimedia to animate notes; interactive examples
13	Cross-site collaborative projects through satellite / web
14	Remote / web-based computing;

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At one extreme is the traditional classroom-chalkboard-lecture-homework-test system. At the other is the paperless, connected environment where students learn over the web or satellite-based course delivery, and all homework and tests use dynamic multimedia. In between are scenarios where the teacher demonstrates methods using a computer in the classroom, lectures off electronic presentations, or where students bring laptop computers to class and everyone participates in interactive problem-solving. The use of multimedia to enhance student interest and comprehension is also a topic of intense interest.

In our environment, both the extremes are generally rejected. Student reactions on anonymous surveys are strongly negative to the idea of electronic presentations replacing chalkboard/white board presentations; and the idea of the live instructor being replaced by a "talking head" on a computer is viewed with extreme negativity and concern by students. The use of multimedia for animated presentations is viewed as unduly time-consuming. While students each possess computers, the idea of bringing laptop computers to class is viewed as distracting. While our classrooms include electronic projectors, students get bored if instructors try to demonstrate the workings of specific software items. Everyone has access to high-speed internet, and uses it for various purposes.

A general idea of how technology is used in our courses is given in Figure 1, from Ref. [11].

IV. Examples of the Technology-Based Virtual Laboratory

Several examples of the technology-based virtual laboratory which we use include:

- Utilization of the same examples across courses, both horizontally and vertically to provide perspectives in analysis.
- Utilization of computers to run engineering codes or examples that require students to make and rationalize the engineering implications of the problem, similar to writing engineering papers or reports
- Derivation versus utilization as a means of introducing concepts for the first time

Experience accumulated from several teachings of aerospace courses at all levels from freshman to graduate, and subjects ranging from the abstract to the hands-on, is discussed. While the classes discussed herein are Aerospace Engineering classes, the techniques are applicable across any engineering discipline. In Table 3, below, the ITULs used in various courses so far, are summarized.

Table 3: Technology levels applied to various courses in aerospace engineering.

Course	ITUL
AE1350 Introduction to AE	1,2, 4-6,9
AE2020 Low Speed Aerodynamics	1,2,4,5,9,11,12
AE3021 High Speed Aerodynamics	1,2,4-6,8, 9,14
AE4200 Vibration & Flutter	1,2,4,5,9,11,12,14
AE6030 Unsteady Aerodynamics	1,2,4,5,6,8,9
AE6020 High Speed Aerodynamics	1,2,4,5,8,9,11,14
AE6052 Flow Diagnostics & Control	2,4,5,6,9,11

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IV a. Usage of Examples Across Courses

This method requires that the instructor have taught other courses in the curriculum, and/or coordinate with other instructors. For example, the idea of the pressure distribution around an airfoil shape, can be used in several courses and contexts. At the beginning, the distribution may be just given in the freshman introduction course, with some rudimentary examples of calculating the pressure coefficient. In the sophomore level Low Speed Aerodynamics class, and the junior High Speed Aerodynamics class, students are asked to interpret, compare, check against predictions, and use knowledge of the pressure distributions. In the senior course on Vibration and Flutter, students are faced with results on pressure distributions from computational codes and experiments, and asked to interpret them, with increasing levels of complexity thrown in. In the graduate level theory and experimental classes, students must create the prediction and measurement parameter sets to ensure meaningful and precise capture of such distributions, bearing in mind the complexities and pitfalls which may be encountered. Technology plays a role in each of these examples, ranging from simple PC-based calculations to high-speed computation and actual laboratory / wind tunnel measurements; however, the benefits multiply when the (checked) work of the graduate and senior classes is used as examples by the freshman through junior classes. The internet, in the form of Digital Library archives on ADL, provides a convenient medium to transfer the knowledge across levels and disciplines.

IV b. Utilization of computers to run engineering codes or examples

Here we mean the types of computer programs which require fairly heavy computational resources. In every engineering school with a graduate research program, there are many "routine" test cases computed in research projects to check methods: these are not useful for research publication. However, they are exactly the kinds of results needed to educate undergraduates on what is to be expected using current theory. The usual difficulty is that such codes and results reside on special-purpose computer systems, locked away from undergraduates. Again, technology provides convenient answers: by means of the internet, these results can be conveniently translated to undergraduate material. Internet-based access to advanced computing resources is a tougher problem, but one which we have been addressing: a new Beowulf Cluster system has been funded out of Institutional Technology fees for 2001, based on competitive peer-reviewed proposals.

Results from experimental facilities can be used to provide dramatic reinforcement of theoretical concepts. Flow visualization images, showing relatively mundane phenomena such as streaklines over an airfoil section during a pitch change, can provide the equivalent of several weeks of on-the-job "real-life" experience to undergraduates. In the early 1990s, we tried incorporating dynamic flow images into problem sets used in undergraduate core courses [11]. This worked extremely well, but the technology posed difficulties because it was based on cumbersome movie-making software which eventually became incompatible with updates of operating systems for later computers. This illustrates one of the pitfalls of going too far to the leading edge of technology. Today, animated-GIF sequences are used over the internet to provide flow-visualization experience to any user through the ADL pages.

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To be useful, such assignments require students to make and rationalize the engineering implications of the problem, similar to writing engineering papers or reports. This again worked very well in the undergraduate courses, where students were asked to calculate the strength of a vortex, or the velocity distribution across a nozzle flow, from actual image sequences of chalk dust on a water surface. The experience also provided some interesting feedback on what kinds of revelations came to students as a result of working these problems.

IV c. Derivation versus utilization as a means of introducing concepts for the first time

In the core courses of most engineering disciplines, teachers face a difficult dilemma. Logical exposition of the material requires that the theory be presented in step-by-step mathematical derivations, before students are asked to use the theory to solve example problems. This is a very difficult process for most undergraduates, who are "inductive learners" at that age. It would be nice if every student could have "practical, on-the-job experience" with the subject before learning the theory; however, this is difficult, given the time crunch of the curriculum. Technology provides the answer. In Ref. [11] we showed how a simple lifting-line calculation of the lift distribution on a wing, could be used to teach aerodynamics to students, starting in the second week of the quarter when they were learning low-speed aerodynamics. Long before they were taught about Thin Airfoil Theory and Lifting Line Theory, these junior-level students had each gained a few weeks of experience in using this code to design wings to meet given specifications. The process was iterative, and we estimate that each student had to run the calculation over 100 times before they were satisfied with their wing designs. In the process, they gained excellent insight on the role played by various parameters such as Aspect Ratio, Taper Ratio, etc, in the aerodynamic performance of a wing. When these students were introduced to the intricate theory behind these calculations, they learned it with alacrity, an extremely unusual experience in a course at that level. The result was that, despite the expenditure of several initial classes to provide results sans theory, the students were able to learn much more material than their peers who were taught through the traditional theory-application sequence. The literature confirms these findings, as an example of how "global learners" and "inductive learners" learn better when they can see the whole problem, and practice extensively.

V. Case Study – How to Adapt Classroom Notes to Concept Engine Format

Consider the topic on a syllabus entitled "Unsteady Thin Airfoil Theory in Incompressible Flows". This topic contains a diverse set of mathematics: differential equations, trigonometry, complex numbers, and the current curriculum prescribes that a derivation be undertaken so that the students understand the underlying physics of the problem. In a typical classroom lecture, this material would appeal to the Divergent and Assimilation learners (based on Kolb's learning style classifications), but would probably not be readily absorbed by the Accommodation and Convergent learners.

Table 4. Kolb Learning Style and Relevant Web Formats for Effective Learning [10]

Kolb Learning Style	Description	Web-Learning Format
Accommodators	• Prefer concrete experience and active experimentation	• Interactive codes with ability to change variables

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		and view outcomes • Examples of real-world applications
Assimilators	• Prefer accurate organized delivery of material • Respectful of the "expert" • Like to know the "right" answer to the problem without experimentation	• Detailed lecture material provided in a neat orderly fashion • Tutorals with provided answers
Convergers	• Like to understand the relevancy of problem (how it works) • Prefers detailed information on operation	• Research papers • Examples of real-world applications
Divergers	• Like to understand why something works • Prefers to explore • Likes information to be detailed, systematic and reasonsed	• Interactive codes with ability to change variables and view outcomes • Detailed lecture material provided in a neat orderly fashion

VI. Role of technology is examined in catering to the learning styles of individual students

Using the web, this material can be presented and augmented to reach all of these learner types. In addition to the actual lecture notes, there are a number of different methods to present this material. Lecture notes are considered to be "audio" input to the learner, as their form is verbal (words). As seen in Table 2, examples of real-world applications would help Accommodators and Convergers to relate to the material. For the unsteady airfoil theory, the application of the theory to the aerodynamics of a hovering rotor (Loewy's Theory), would be a productive example, as well as how to predict the aerodynamics in a wing flutter problem. Interactive codes that permit the student to play with the varying parameters help Accommodators and Divergers to understand the implications of the unsteady aerodynamics. For the unsteady aerodynamics theory, a Java script or applet that permits the student to change the amplitude or reduced frequency of an airfoil permits the student to observe the impact of the changes in the variables. These forms are considered to be very important to the visually-stimulated learner. For all learner groups, tutorals or worked problems to show students how to transfer the theory to application is always valuable.

VII. Assessment Methods

Engineering education involves a complex learning environment with many variables; thus a design experiment [**Error! Bookmark not defined.**] is the key to understanding the assessment process. Mixed-mode evaluation [11] should be applied in an iterative manner to continuously monitor and refine both the technology enhancement system and the assessment process. The assessment process evaluates not only how individuals are assimilating depth and breadth of technical knowledge, but also how the students perceive their learning growth.

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Quantitative Methods: Methods to track the utilization of technology include the more traditional anonymous surveys conducted at the end of each course. Quantitative measure of these items via a statistical analysis is the best method, as they are not items that can be left to the student and be accurately tracked.
Qualitative Methods: Since the analysis of the complex educational process requires an in-depth study of the interaction of the participants with the faculty and the learning environment, one must augment the quantitative methods with qualitative methods of assessment. Criteria for these methods are set forth by NSF [**Error! Bookmark not defined.**, 11, 12]. In this context, student responses should be correlated with faculty observations to provide an in-context scenario. For example, in the evaluation of student learning, faculty comments on the course, quiz questions, and observations might be correlated with student responses.
Our qualitative methods include: a) end-of-semester course evaluations administered by the Center for Teaching & Learning (CETL), b) mid-semester evaluations, c) free-form responses, d) student responses on "specialized" test questions, and e) graduating-student surveys (Institute Assessment Office). We also continue to obtain samples of every test, assignment etc. from each course as they are collected for ABET assessment.

Free-form survey questions are organized to answer the following questions related to ABET outcomes:

1. How well are the basic features of the program working? How well are students getting to the basic information intended for them? Are they finding the right resources? Are they using them?
2. Analysis Methods: Are students using the analytical methods taught in each course, and are they transferring skills across courses?
3. Integration: How well are students combining concepts and methods from different courses and applying them to new situations?
4. Knowledge: Given new applications, how well are students able to understand the situation, analyze in depth, relate to previous experience, and solve the problems?
5. Insight: Given new technology, how well are students able to capture the key issues, relate them to concepts previously studied, and attack the problem in a focused way?
6. Vision and innovation: How well are students able to think laterally and see opportunities in combining approaches which have not been studied, but which make sense within the physics/mathematics of the problem?

Sets of questions have been tried out in several e-mail surveys, obtaining free-form responses over the past year. These results continue to be analyzed to refine the appropriate manner to ask the question to eliminate misunderstanding, bias, and to provide a consistent standard in the test questions across instructors and years to provide triangulation of results.

VIII. Discussion

Several courses within the Aerospace Engineering curriculum at Georgia Tech have been transformed to utilize one or more of these web-based formats to study their impact on learning. These courses include both undergraduate (Low Speed Aerodynamics, High Speed

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Aerodynamics, Experimental Aerodynamics and Introduction to Aeroelasticity) and first-year graduate classes (Unsteady Aerodynamics and High-Speed Aerodynamics).

For all these classes, students were asked to read the lecture notes on the web before the actual lecture. In surveys taken at the end of the semester, it is apparent that the majority (80+%) did not read the assignments. In one class, as reported in [13], pop quizzes were given as an incentive to read the assignments, but this generated some adverse response (45% over two classes). It should be noted that in these and other classes, students who reported that they did take the time to read the assignments felt that they understood the material better than they understood other material from other classes. Students who didn't read the material cited the pressure from too many other classes. These comments crossed the undergraduate class levels, as well as the graduate classes as well.

The interactive codes provided for these classes were utilized in homework assignments. In particular, the assignments were designed to address the following ABET 2000 Criterion:

- An ability to apply knowledge of mathematics, science and engineering
- An ability to design and conduct experiments, as well as to analyze and interpret data
- An ability to identify, formulate and solve engineering problems
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In addition, codes utilized in one course were revisited in subsequent classes to provide a different perspective of the material. In addition to running the codes and observing the results, students were asked to make engineering plots and to extract conclusions. These conclusions required that students write explanatory paragraphs to aid in writing engineering technical reports. From the responses of the students, it was clear that all four learning styles were present in the classes. Some students welcomed the challenge, but some felt that the "open-endedness" of the problems were counterproductive to understanding the material.

The tutorials and worked examples were greeted with an almost unanimous positive response. In fact, the most common comment was that the students wanted more examples, if possible.

IX. Concluding Remarks

Our work confirms the intuitive idea that applying technology in an appropriate manner can enhance learning in engineering courses substantially. These enhancements are key to meeting and exceeding ABET requirements, and are in accordance with the goals of ABET2000. Several specific aspects have come to light:

1. The need for systematic study of learner types and learning styles as part of technology usage in the curriculum.
2. The utility of technology-based methods in addressing learners with different styles.
3. The utility of technology in combining course work with assessment of learning.
4. The importance and feasibility of combining qualitative and quantitative assessment tools to address learning, in a manner consistent with ABET goals.
5. The need to choose appropriate levels of technology utilization levels for each course.

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Usage of technology in the curriculum has opened to way to integrate design into engineering at a very early stage, enable learning across disciplines as an ingrained attribute of engineering students, and integrate learning across levels. The next challenge is to get more instructors to recognize that the students of today, armed with the experience of such courses, can learn in ways different, and possibly far more effective, than the traditional and fragmented methods still used in many courses.

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Biographical Sketches

NARAYANAN KOMERATH

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

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Marilyn J. Smith earned her Ph.D. in aerospace engineering at the Georgia Institute of Technology in 1994. She joined the faculty as an Assistant Professor in the School of Aerospace Engineering at Georgia Tech in 1997 after fifteen years of industry experience at Lockheed-Georgia (now LMAS), McDonnell-Douglas Helicopter (now Boeing Helicopter-Mesa), and the Georgia Tech Research Institute. She was awarded the 1999 Outstanding Faculty Member by the GIT Women's Leadership Conference. She is an Associate Fellow of AIAA and a past member of the AHS Fluids Technical Committee.

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