Aerospace Engineering: Integrator for Cross-Disciplinary Learning

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Abstract

Aerospace Engineers have a tradition of innovating across discipline boundaries. Each new flight vehicle design is a challenge requiring the application of advances in different disciplines. The fast-changing technological marketplace makes it critical to prepare students to absorb and integrate knowledge from any discipline. This skill will be crucial to their ability to analyze problems and develop new concepts. The basic question facing engineering educators is: *"How will we teach learners to seek and grasp the fundamentals of new disciplines and to use them appropriately to solve problems?"* This issue faces the tough constraints of time, the imperative for depth, the need for sequential presentation of fundamental knowledge, the maturity of the learner, and the ability of any given instructor to teach multiple disciplines. A system where students learn, by iteration, to solve problems across disciplines is being developed at the Georgia Institute of Technology. The Internet is used as a knowledge locator and integration tool to supplement traditional learning methods. A growing resource called the Aerospace Digital Library (http://www.adl.gatech.edu) is being used by learners at all levels. A learner-centered gateway, set at the level of a college freshman, links the fundamental logic of technical disciplines to the leading edge of technology. Using a Concept Engine structure, learners can navigate from the basics to the leading edge of multiple disciplines. In this paper, the issues of catering to differing learner styles, and the experience of learners at different levels using the ADL, are discussed.

I. Introduction

Students often find it difficult to integrate and apply knowledge from previous courses in a new context. This is especially a problem with classic curricula, which are based on the assumption of a student's vertical integration of knowledge from previous courses. Industry leaders[1] are beginning to recognize this growing problem as technology expands ever faster. These concerns have been translated into the ABET 2000 outcome criteria[2]. There is an urgent need for engineers who can assimilate knowledge and translate it efficiently across and upward along discipline paths to achieve levels of experience lost through retirement and the lack of full-production aircraft design programs. In order to achieve these ambitious goals, it is imperative that each student learns to the best of their ability throughout their undergraduate experience. This is obviously not the case in current practice in all levels of student performance. The central theme of achieving these goals is the recognition that each individual student has a *combination* of the traits associated with different types of learners. What is needed is a teaching approach that adapts to individual learning styles without the need for a radical change in the current curriculum. This paper addresses one teaching approach that can be utilized to achieve these goals, given the constraint that the current engineering curricula remain in place.

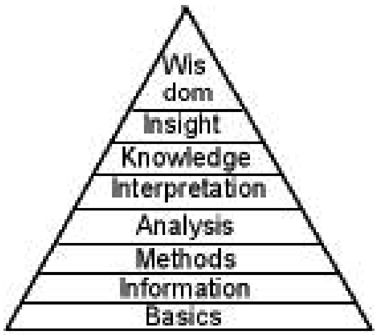

Figure 1: The evolving "Knowledge Worker". Industry views a progression of the knowledge level of engineers from the "Methods & Analysis" level of the past to the "Analysis & Interpretation" level of today, on to the "Knowledge & Insight" functions of the future. From Ref. 1.

II. Pertinent Learning Issues

Before developing an approach to help students learn, it is necessary to understand *how engineering students learn*. There is a severe lack of understanding of the specific motivations and learning issues of engineering undergraduates. Experiential learning, team projects and real-life examples motivate students in the short term, but further study is needed on how they integrate learning across levels (vertically) or disciplines (horizontally), and on standards of learning and achievement to which students and teachers can aspire. Using anecdotal evidence to implement target standards, usually erring on the side of mediocrity, is very detrimental to engineering education and research, as pointed out by Labaree[3].

There are several learning issues in context to engineering students that need to be addressed prior to developing any teaching approach. They include the classification of learning styles of engineering students, how should the material best be presented to promote learning, and how often should the material be revisited. In addition, the ABET 2000 criteria specifically require that students not only learn the material, but learn to apply the material to new applications that have not been previously encountered in the classroom. These criteria are shown in Table 1 along with guidance on achieving these criteria through the utilization of the web. Cognizance of research on how knowledge is transferred across disciplines or situations is therefore necessary.

II.1 Engineering Student Learning Styles

Felder and Silverman[4] 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[5] 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.

The issue of attracting and retaining under-represented groups is extremely important. In Keri[5], male students preferred peer and instructor involvement in projects and life experiences, while females preferred more reading and highly organized learning. However, in Philbin et al[6] males preferred traditional, more abstract teaching styles, while women preferred more hands-on experience. Therefore, it is important for the engineering educator to encompass all learning styles within their courses, as retention of students can be severely affected if any particular learning group is excluded.

II.2 Presentation of Engineering Material

It is clear that the presentation of material in different forms is very important in learning the complex material typically present in engineering courses. Engestroem et al[7] studied the vertical and horizontal dimensions in the development of expertise. They analyzed three cases of collaborative problem solving and learning in team environments. The cases were based on recordings and observations conducted in a municipal welfare and health center, a primary school, and an industrial plant. The understanding and acquisition of expertise involved polycontextuality (engagement in multiple ongoing tasks) and boundary crossing (transporting of ideas, concepts, and instruments from seemingly unrelated domains into the domain of focal inquiry). They argued that focusing on the objects and mediating artifacts of actual processes of collaborative work and problem solving) may be useful in articulating the horizontal dimension of expertise.

II.3 Iteration of Material

Several researchers cite the importance of spaced repetition (iteration) of material[8,9] over long time periods to enhance long-term memory. The issue of providing opportunities for iterative learning during formal education appears to have been neglected, probably because such schemes were not practical in a traditional curricular structure built on “pre-requisites”. Technological advances allow such vertically-integrated schemes to be considered now, with students learning by iteration, and their progress in specific disciplines assessed through a longer period than just one specific course.

II.4 Transfer of Knowledge

One apparent effect of curricular compression is that students resort more to memorization at a high cost in comprehension. Effective learning requires that students get beyond rote memorization and understand the scientific principles. Students who memorize have little basis for the transfer of information from one class to another (near transfer) or from school to work (far transfer)[10]. To master this material, a major investment of time by the student is required – even by "talented" students[11]. Again, in an adaptive integrated curriculum, near and far transfer can be made routine and much less costly. Singley et al[12] describe the time required to learn the material as being proportional to the amount of material to be learned. This assertion is interesting in that it reflects the traditional view of sequential learning. The authors’ experience with an iterative scheme[13, 14] is that a re-organization of the order of presentation, homework and evaluation schemes can produce a large increase in the amount of “material” absorbed by students during a set time period (college semester). Given curricular time constraints, the problem is to ensure that the time spent on learning be quality time; students must retain information to which they are exposed. 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, liking new challenges, to being performance-oriented and concerned mainly about mistakes and their impact on grades. Material must be presented in multiple contexts for clarity to ensure that students can retrieve information in non-context (near and far transfer) problems[15, 16].

III. Implementation

It is clear from the previous discussion that engineering material must be presented in multiple learning styles to capture the spectrum of students in the classroom, be repeated at given intervals, and be presented in multiple forms to assist students in knowledge transfer. This is a daunting prospect given the curricula constraints. The utilization of the Internet or web-assisted learning is a natural means through which classroom time can be leveraged. However, the manner of presentation - beyond the learning styles themselves - is also important. The method of spatial presentation of material has been shown[17] to have a direct impact on learning rate and retention. That is, material presented both horizontally and vertically (e.g., a 3X3 array) is learned easier and faster than material in a vertical presentation manner (e.g., a 1X9 array). Recent research[18, 19] 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 professor's lecture style. 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[20], as well as experiences with web-based learning by the authors[21], 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.

After several iterations in concert with student input, the method of presentation has been refined to reach the different learner styles of engineering students. The core of the material is presented in individual modules called Concept Engines (CE). These Concept Engines are basic essays that address one single topic. For example, a Concept Engine may discuss Prandtl's Lifting Line Theory. From a presentation viewpoint, the material presented should be simply a discussion of the theory itself, with the assumption that the reader recalls the concept of Kelvin's Theory, the Biot-Savart Law, and basic theory of finite wings. This presentation style is coincident with some learning styles, but may be tedious or frustrating to other learning styles. However, using the web, the concept engine can be adapted to suit all combinations of learning styles by providing different learning stimuli to the reader, as shown in Table 2.

IV. Student Perceptions

The authors' experience[21] has found that overall, using the web-based material in conjunction with classroom lectures that are regularly scheduled (typical curriculum) or scheduled as needed (modified curriculum), promotes deeper understanding of complex material. These web-based Concept Engines were examined in courses at different levels in the undergraduate and graduate curriculum. Since students at this level are adults of high intelligence, high value has been placed on their comments and responses to surveys and optional questionnaires. These qualitative responses have been much more meaningful than the quantitative survey responses that were also done in these classes.

IV.1 Freshman Level Student Response

The Aerospace Engineering freshmen are required to take an Introduction to Aerospace Engineering course during their first or second semester at Georgia Tech. This class is their first exposure to Aerospace Engineering at the college level and is probably their first engineering course as well.

When asked how much of their learning was each source, the composite and near-unanimous answer of the students was that 60% of their learning was from attending class, 10-15% from the web-posted notes, perhaps 10-15% from out-of-class discussions including e-mail exchanges with the instructor, etc., about 10% from independent exploration, and only about 5% from the textbook. The web-based notes were cited as being valuable for a number of reasons: “reference” in case of doubts about what they wrote down in class, clarifications when doubts arose on assignment, iterating between sources to study for tests, and links to other web resources. Some cited the experience of exploring on their own through the whole resource at the beginning; this is a sign of global learning being facilitated. The primary comment associated here was that the textbook assumed that the students knew much more about the technical nomenclature and mathematics than they did. The textbook is a very popular introductory aerospace engineering text, and the instructors remain convinced that it will prove an invaluable reference to the students in years to come. However, the constraints of a sequential textbook force it to present material at a level and complexity which are seen to be “too technical” by the first-year student. Students also believed that they were modifying their learning habits from high school to be more creative or thorough in finding information needed for assignments. Most did not read the notes ahead of time, though some agreed on thinking about that question that this would be a great idea.

The students accessed the concept engines at different frequencies, from four times over the fifteen-week period to “six or seven times per week”. The level at which the web was utilized appears to correlate with the computer expertise level of the student. Older students, and students who were timid about computers tended to access the system less.

About 25% of the students reported trouble finding material they needed for their assignments due to the large amount of data available within the system. These correlated roughly to preferences for sequentially presented material and instructions such as those given in pilot manuals.

IV.2 Upperclassmen Student Response

The concept engines were utilized in several upper class courses repeatedly with different professors, in particular AE3021, High Speed Aerodynamics. Students reported using the concept engines from just a few times the entire semester to practically every day for all the courses they were taking. The primary problem with these concept engines is that most students do not feel that they have the time to access the notes, citing heavy course loads. For some, the concept of being asked to explore new material outside the traditional classroom lecture created a negative view towards the process. Smith[21] reported similar findings in a graduating senior core class when she changed from a lecture format to an interactive format suggested by other engineering researchers[22]. From correlation to the remainder of the discussion provided by these students, it is clear that they are definitely performance-oriented learners who object to spending time that they perceive as "wasted" in earning a grade.

Many students felt overwhelmed by the amount of knowledge available on the Internet, either through the concept engines or via search engine results. They stated that they lacked a clear focus for determining what was important and what was not important. Further, notation variations from the required course text or from the lecture notes in the class appeared to confuse some of the students. This is not surprising: what is surprising is that so few cited this difficulty. The ability to study material through different approaches and different nomenclatures is an encouraging sign for experiments in cross-disciplinary learning.

Some of the students who had the top grades provided an interesting dichotomy of responses. Some lauded the ability to access in-depth derivations on topics, going straight to the graduate level, and commented that this was a unique feature of this resource. Others showed extreme negativity towards web-based material, citing the (unfounded) fear that this was an attempt to take the human instructor out of the classroom. It may be that students who have refined very successful studying methods are loath to change them at an advanced stage of their undergraduate curriculum.

IV.3 Graduate Level Student Response

The web-based notes were utilized in AE6030 (Unsteady Aerodynamics) and AE6020 (High Speed Aerodynamics). The Unsteady Aerodynamics class relies substantially on mathematical derivations and the understanding of high level mathematics, while the High Speed Aerodynamics class material has been seen at the undergraduate level and focuses more on applications and the understanding of concepts. In these classes, there was a diverse range of utilization of the web-based material, from every class to once a week. All students felt that the additional availability of the Concept Engines helped in understanding the material, primarily by providing a concise set of notes similar to those that would be taken by themselves in class.

About half the students were international students whose first language was not English. These students indicated that the Concept Engines were especially valuable in that they permitted more "listening and learning" in class, rather than the typical focus of copying notes from the board. These students felt less pressured and indicated that they felt that they learned more of the material because of this.

For these classes, the classroom presentation and Concept Engines were presented in two styles:

- Traditional classroom lectures with shorter web notes
- Longer, more detailed web notes that read like a classroom lecture and were required reading prior to the class. Only questions on the material were answered in class, and more applications were discussed during the freed classroom time.

Interestingly, a third of the students responding liked each of the two types, and the remaining third expressed no preference. This clearly indicates the presence of the different learning styles of the students. Of the students who expressed the preference of the longer notes, their reason was that it presented more details of the material in one location, particularly in the derivations and explanations. The majority of the students did not read ahead for all the lectures, claiming the pressure of research or other classes, thus negating some of the benefits of the second method of presentation. When asked what they would change about the concept engines, the students again revealed different learning styles by requesting different presentation methods (move derivations to an appendix, add more information into the main pages, add more figures, etc.).

Students were provided independent-thinking assignments during the semester. About half responded that they utilized the web-based information first, while the other half reported going straight to the traditional library. This division appears in both foreign and American students equally.

IV.4 Cross-Disciplinary Learning

While the experience reported to date is from traditional discipline courses in individual disciplines, the impact of the ADL in cross-disciplinary problem solving is being felt at various levels. In the freshman course on Introduction to Aerospace Engineering, students are asked to find data and ideas from various resources, regardless of disciplines, to solve problems using basic physics. At this level students find this unremarkable since they have not yet been channeled into disciplinary preferences. They see all assignments as being related to aerospace engineering, and they view the issue as being primarily one of finding information on the web. A few commented that at the end of the course, when they had completed their conceptual design of an aircraft of their choice, that they began to realize that they had learned an enormous amount about how airplanes were designed and flew. The basic ingredients of cross-disciplinary problem solving are this ingrained quite easily at this level.

In courses on Flow Diagnostics and Control, Komerath[21] has found that senior-level students perform quite well in reading and thinking ahead on material from diverse disciplines but welcome integrative lectures on material where they have not taken formal courses, such as digital signal processing. Assignments in Flow Control involving ideas from different fields show that students will readily accept learning in different fields, if material is available in a compact form to enable them to focus on key issues. In senior-level aeroelasticity, students are just beginning to be able to solve large-scale problems involving structures, aerodynamics and computational methods, as web-based access to different levels of courses in solid mechanics, and to large-scale computations, are added to the web-based resources.

In the graduate unsteady aerodynamics course, students in past semesters reacted negatively to sections where they were asked to learn topics on high angle of attack aerodynamics, viewing these as being outside what they were "supposed to" learn. This was based on their reading of textbooks, which stay narrowly focused. With web-based introductory material provided, no such resistance is seen, and students quickly grasp the key issues in these areas.

Anecdotal evidence is accumulating on the usage of ADL by students outside aerospace engineering. A recent analysis of usage statistics showed that while usage was heavy from inside the institute as part of the courses, over 70% of total usage came from outside the United States. Students cited examples where friends in Electrical Engineering, for example, were using the simple and compact presentations on ADL regarding Digital Signal Processing to improve their understanding of the basic issues and applications of this field.

V. Concluding Remarks

Performance data has been presented from a large and ambitious system that has been developed at Georgia Tech. This system is intended to provide a comprehensive solution to various issues within the constraints of present university curricular structure, while allowing the interested teacher and student to fly far beyond the usual confines of such curricula. From the student perceptions and feedback presented in the previous section, several conclusions can be extrapolated:

- First, the faculty must present the information very carefully. For the Concept Engines that correlate to the lecture material, this is a straightforward application. Syllabi with direct links to the appropriate concept module under discussion have been found to be very successful. However, when students must solve the independent problems that they will encounter in their future jobs, and as required by ABET, the professor cannot provide a direct link for them. To do so would defeat the purpose of the problem. Instead, some class discussion or examples of how to solve critical or independent thinking problems need to be presented to the students at the outset of the course. Providing links to multiple sources of similar information may also be helpful.

- Students at the beginning of their undergraduate or graduate course work should be exposed to this methodology rather than waiting until upper-level courses are reached. Students may develop a negative attitude when material is presented differently than they are used to in similar courses. This is particularly true of the effort required in the independent or critical thinking problems.

- This method of presentation has great benefits for a student for whom English is a second language. The ability to be able to listen and comprehend the material without the worry of copying material down provides a level of academic security.

The results presented here are qualitative, based on the student feedback in courses where this technology has been applied. Further research is needed to determine if a quantitative correlation to learning is seen.

Indicators presented above show that the resources are well utilized by current students and that bold moves into large-scale problem-solving across disciplines is a natural next step. Unfortunately, it appears that people in disciplines outside AE tend to be far more narrowly specialized, and they are often unable to comprehend the idea that one can reach out and learn fundamentals across disciplines and solve problems competently. This issue requires careful examination.

Table 1: ABET2000 Criterion 3 – Program Outcomes and Assessment[2]

ABET Outcome	ADL features relevant to the 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 • understand professional & ethical responsibility • communicate effectively	• Integrate knowledge across levels. • Design-based assignments in freshman courses. • Teams formed to solve problems in courses. • Requirement to seek solution techniques well beyond for confines of the immediate course. • Vertically integrated curriculum resources enable functioning of multi-level, multidisciplinary teams. • Open-ended problems require communication / presentation skills.
The broad education necessary to • understand the impact of engineering solutions in a global and societal context	Ability to deal with "softer", less quantitatively precise problems through integrated approach
• a recognition of the need for, and an ability to engage in life-long learning	Ingrain the idea of integrating knowledge and learning through preferred learning style.
• a knowledge of contemporary issues	State-of-the-art accessed & distilled via web links.
Ability to use the techniques, skills, and modern tools necessary for engineering practice.	Access to leading edge computational techniques through Beowulf Cluster computing.

Table 2: Learner Styles & Concept Engine Relationship

Interface	**Astronaut**	**Eagle**	**Barnstormer**	**Rocket Scientist**
Learner Style	Sensory/ sequential	Global / Intuitive	Global / sensory	Intuitive
Emphasis / Presentation	Sequential Inductive organization.	Site-maps -free to pick precise items quickly	Perspective. Theory linked: problem-based approach.	Theory. Hyperlinked derivations; use of mathematics.
Reasoning	Inductive /Active Processing	Inductive / deductive	Inductive/ deductive	Deductive/ Reflective Processing
Resource Types	Modules Point summaries Re-iteration Examples	Database subject; glossaries; Insight Hyperbolic Tree; Site Maps, charts.	Concept Engines, Data Graphical Illus. Examples, Calculators	Theorems; proofs. Logic, Original papers. Concept Engines. History.
Inp. emphasis	Auditory	Visual	Kinesthetic	Auditory

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