INTEGRATED KNOWLEDGE RESOURCES FOR CROSS-DISCIPLINARY LEARNING

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Abstract *¾ The evolving technological marketplace demands that engineers absorb and integrate knowledge from many disciplines. The central issue is how learners should seek and grasp the fundamentals of new disciplines and use them appropriately to solve problems, given the constraints of time, the imperatives for depth, learner maturity, and instructor ability to teach across disciplines. A decade of experiments on this issue has generated an Aerospace Digital Library nucleus, which is being used by learners across the world. A learner-centered gateway links the fundamentals of technical disciplines to the leading edge of technology. While a generation of students is learning to solve problems across disciplines naturally, severe obstacles remain in conveying the idea of cross-disciplinary learning to many specialist educators. Reactions from education specialists are contrasted with experience from students at the undergraduate and graduate levels and discussions with alumni utilizing the material. Student reaction and experience with the system are also discussed.*

Index Terms *¾ Aerospace Digital Library, Learning across disciplines, Iterative Learning.*

INTRODUCTION

Professor Stephen Hawking [1] succinctly identifies the conflict between breadth and depth which limits curricular advancement in technical disciplines: *"In the nineteenth and twentieth centuries, science became too technical and mathematical for the philosophers, or anyone else except a few specialists"*. The fast-changing technological marketplace makes it critical for engineers to be able to work on diverse problems across many disciplines without formal courses in each. Today's curricula assume that students will absorb and integrate material vertically through a series of lectures and courses, and therefore problem-solving requires taking several courses in the discipline concerned. Even in individual disciplines, students often find it difficult to integrate and apply knowledge from previous courses in a new context. Since most of today's educators were themselves educated in the above environment, there is resistance to evaluating alternative approaches that might be more appropriate.

The Aerospace Digital Library (ADL) (www.adl.gatech.edu) is a learner-centered resource for learning engineering fundamentals and solving problems across levels and disciplines. Specific objectives of the project described here are:

- Develop a core of fundamental knowledge on several disciplines accessible through the internet, sufficient to form a useful learning resource for learners at various levels.
- Develop user experience in courses and research programs as a learning resource .
- Assess learning methods and curricular structures enabled by Items 1 & 2.
- Test hypotheses about self-sustainment, growth and self-organization of a large knowledge resource.

PREVIOUS WORK

The internet offers a promising medium to help cross-disciplinary problem-solving. References. [2-7] summarize the deliberations on the development of the National Digital Libraries to accelerate learning from digital sources. Approximately 43 funded projects have come into being on the NSDL, in addition to several large projects under the National Science Foundation's Digital Libraries Initiatives 1 and 2. While DLs were originally intended [2] to incorporate inquiry and collaborative learning in large classes, help assess learning outcomes, document learning gains at departmental and institutional levels,and provide learning resources directly to undergraduates, a search using the most popular search engines on the internet today for "engineering courses" typically produces over ten thousand "hits", but few (actually only one, at a beta site set up by www.needs.org) [8] from the DL initiatives that provide direct access to curricular modules, and that through search engines rather than through guided learning interfaces. Most of the top 100 "hits" are reports on workshops and projects which declare the need for engineering digital library

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content. Rare is the undergraduate, and even rarer the professional, who digs deeper than 100 into Search Engine results on a given topic.

ADL was originally inspired by the commissioned papers listed in [4], as we sought ideas to enhance learning by presenting the same material iteratively in different classes and problems to complement the traditional sequential curriculum. The DL in this context is a resource which helps the human mind do what it does best: acquire, comprehend and condense knowledge, debate its validity, and use it to solve problems. ADL has been in existence for 2.5 years. Current usage (April 2001) averages several hundred different hits per day. In March 2000, roughly 70% of the usage came from outside Georgia Tech and 18% from outside the United States. Today the usage is more heavily from the US, as usage within our home institution, Georgia Tech, has grown substantially with the progress of students who were exposed to the resource as freshmen. The ADL lacks many formal features of the established DL projects, as it is being developed as needs and spare time of the faculty present themselves, but it does enjoy several features which have proven successful in getting engineering students to use these resources:

1. *A design-centered portal* to the knowledge base that engages the learner's mind, tailored to learners at the undergraduate level and beyond. Immersed in the design process unique to the school, the learner visits each of its disciplines, many times, as demands arise. Guided paths lead to course structures and on to the leading edge of each discipline. This learner-centered structure of an access to the knowledge base is shown in Figure 1.

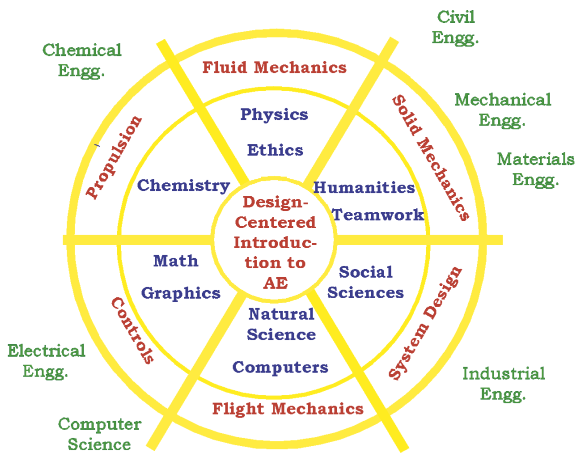

Figure 1: Learner-centered access to the knowledge base from a specific discipline. To the beginning learner, the path to the leading edge of technology lies through an introductory course, the basic sciences, other learning skills, and on through core courses and other disciplines.

2. *A Concept Engine structure* for knowledge transfer across levels and disciplines, providing a centripetal, cohesive dynamic to the ever-expanding knowledge base. This is shown in Figure 2 below.

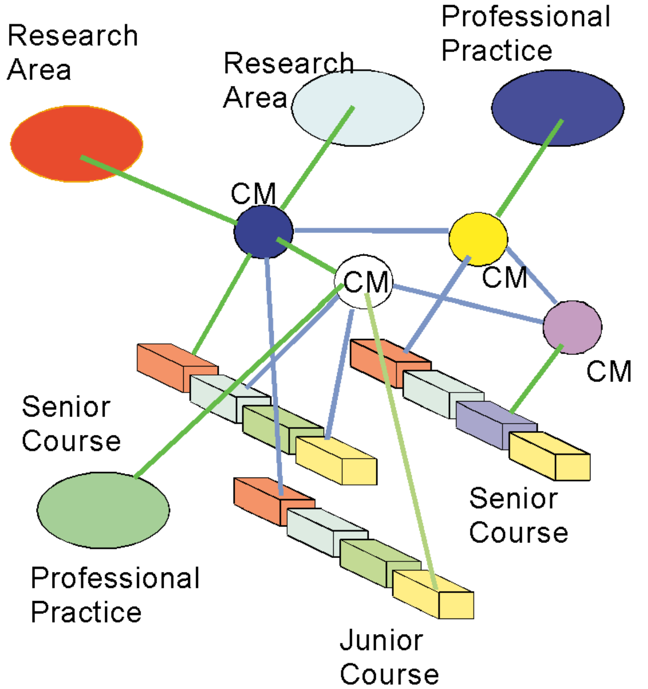

Figure 2: Concept Engine modules tie across the linear sequences of courses, and between professional resources.

3. *A worldwide collection* of basic and advanced knowledge on aerospace engineering. This built up gradually by adding links as they are found, to relevant concept modules or courses. Lists of such resources are developed for each discipline, and each subdiscipline within aerospace engineering. Starting points for such resources are the web pages of institutions specializing in each area, with the intention that each will have its own learner-centered access node eventually.

EVOLUTION OF THE PROJECT

This project has followed the synthesis-first approach of Rechtin [9]. The first step was to develop enough content for students to utilize ADL in their studies and research, and to focus our thinking. As of May '99, ADL provided links to 66 courses across campus and to U. Oklahoma. Links were developed to a superset of DLs worldwide, including NASA, ASEE, AIAA, other Engineering virtual libraries, information resources of the U.S. and other nations, and to university DL centers. By Fall '99, the content was at a stage where students were using these resources across disciplines.
The next steps were to write Concept Engines and cross-link resources. Observation of learners indicates that the

introductory discussions in course notes serve as Concept Engines quite well. The cross-linking process within the Fluid Dynamics/Aerodynamics curriculum primarily focuses on the need for students to review material from previous courses. Examples of student usage of digital resources are given below.

Freshman Design-based Introduction to Aerospace Engineering

In this course students use the internet to find data on aircraft and spacecraft design parameters, and they then use them to get a "feel" for numbers, a simple version of the process of developing benchmark data as part of the conceptual design process. Introductory material is given on pre-developed web resources through the ADL, and links are provided to appropriate resources at NASA, Air Force and aircraft manufacturers' sites. Later in the course, students use the internet in teams of two and post their designs on their own web pages. The evolution of the course and student performance are discussed further in Ref.[10].

Sophomore-level Low-Speed Aerodynamics

This course imparts basic knowledge with illustrations and equations through the ADL. Links are provided to resources developed by several instructors with markedly different teaching styles. Links are also provided to executable programs for computing wing aerodynamics at the websites of other universities, and students are asked to use these to validate their own calculations. Flow visualization resources developed at Georgia Tech are supplemented with resources found elsewhere on the internet. The course content was reorganized to an Iterative format, where students were accelerated in the first few lectures to the point where they were doing wing design calculations and gaining practical experience. With such experience in hand, their receptiveness to the underlying theory became much higher, with an accompanying improvement in performance. Results from this course are discussed in [11].

Junior-level Gas Dynamics and High Speed Aerodynamics

Again, course notes and teaching styles from different instructors are provided through the internet. One valuable aspect of web-based open resources is seen in these course s as students find themselves able to revisit content from the lower level courses. At this level, students are asked to take on larger projects, such as calculating the performance of typical aircraft configurations, then validating those results against the actual performance data on the aircraft.

Senior Aeroelasticity and Flow Diagnostics

At the senior level, the internet allows students to perform projects that involve a greatly increased level of independence and initiative. Both individual and team projects are assigned. Here students are asked to perform projects involving substantial effort in searching for resources using the internet before applying them. Project results are posted as web resources [12].

Graduate Unsteady Aerodynamics and High Speed Aerodynamics

In these two first-year graduate courses, the notes and assignments are provided over the internet in addition to regular classroom lectures and textbooks. Students are encouraged to use internet resources to solve problems, but so far this has been a frustrating experience as students in these classes come with very stiff prejudices regarding learning styles. They have been generally less enthusiastic about open-ended work requiring critical thinking, than undergraduates. This is problematic of students from different ethnic, social, and academic backgrounds.

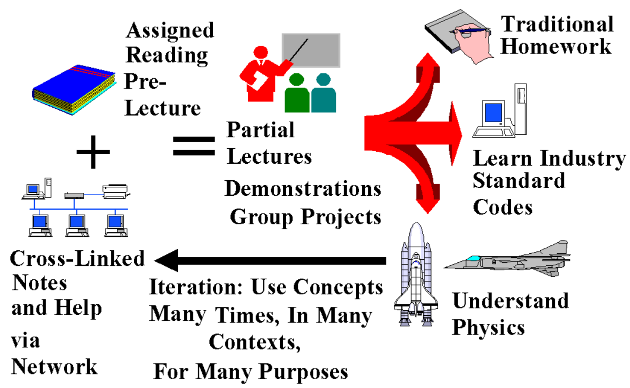

Figure 3: Role of internet-based resources in enhancing learning. Students can gain experience with real-world problem-solving through iteration, while improving physical insight.

Multilevel team projects

Internet usage is heavy in team projects involving students at all matriculation levels. Projects range from those associated with NASA Microgravity Flight Tests, to the development of business plans for Space Commercialization around ideas for technology-based startup firms. Students use the web site as a "Knowledge Management" resource [13], storing project documentation for common access, and using an electronic forum to solve the problem of finding common meeting times. Such projects provide excellent experiences of problem-solving across disciplines; however, the difficulty is that only a small percentage of the total student population participates in such projects, hindering generalization of the experience.

USER EXPERIENCE WITH THE AEROSPACE DIGITAL LIBRARY

User experience at levels from freshman through graduate school at GT is accumulating rapidly, and provides an interesting perspective on how the students' learning habits and expectations are changing in this technological environment. Assessment of the resources is conducted in each class where ADL is used with students responding freely with detailed comments on how their learning styles are evolving. The results are given in [14-15].

The focus of our efforts is on students of engineering at the undergraduate and graduate levels. The active participation of these students is an important strength of our approach. The interests of these students range far outside their chosen disciplines. Links to digital libraries on Shakespearean literature and classical poetry have been used, and the web resources of NASA and other Federal Agencies are popular and heavily used. Web resources at other engineering schools are used, regardless of location. For example, students in High Speed Aerodynamics proudly cited their active discussions with university faculty in Germany about a computer code for their aircraft calculations.

Links to these engineering resources at diverse sites are exchanged amongst faculty. Curiously, none of these has ever included any from the major Digital Library sites. A possible reason is that these resources are hard to find using Search Engines with the key words typically used by students seeking help on homework.

STUDENT PERCEPTIONS

The authors' experience at GIT has found that 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. Open-format student responses have been much more meaningful than the concurrent quantitative survey responses.

Asked how much of their learning was from each source, the composite and near-unanimous answer of the students was 60% of their learning was from attending class; 10-15% from the web-posted notes; perhaps 10-15% from out-of-class discussions, 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 - in particular for foreign students; clarification when doubts arose on assignments; reviewing for tests; and starting locations to other web resources. Some cited the experience of exploring on their own through the whole resource at the beginning - a sign of global learning.

The concept engines were accessed at different levels by the students 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 a preference for sequentially-laid out material and instructions such as those given in pilot manuals.

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. Some students at this level did not feel that they had 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. Findings in the senior aeroelasticity class were similar [12] when the instructor changed from a lecture format to an interactive format suggested by other engineering researchers [16].

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. Surprisingly few cited difficulties with nomenclature and terminology. The ability to study material through different approaches and nomenclatures is an encouraging sign in cross-disciplinary learning.

Students with the highest grades provided an interesting dichotomy of responses. Some loved the ability to access in-depth information, going straight to the graduate level links, 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 successful studying methods do not wish to change them at an advanced stage of their undergraduate matriculation.

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 as they permitted more "listening and learning" in class, rather than the typical focus of copying notes. These students felt less pressured and indicated 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 that 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, 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.).

Reactions from the Professional Community

Here we find an interesting dichotomy. Alumni of engineering programs such as ours typically appear to be very positive and comfortable with the ADL resources, expressing delight at finding course notes accessible from their desks. There is as yet no evidence of usage in their day-to-day problem-solving, except to seek data on specific issues, or to get copies of research papers. These users have also taken the initiative to contribute several items for informal publication, urging their usage in classes.

Usage by other professionals is not yet known to be significant. This is probably a sign of current professional practice, where one is expected to take a Short Course to train oneself in another discipline before undertaking any problem-solving in that discipline. The idea of being able to find reliable in-depth resources and guidance on the web is new.

At the level of other faculty, there are several, as seen from NSF Proposal Review Panel comments, who recognize the importance and relevance of such a resource. At the same time, there is an equally large population of reviewers who seem barely able to read about the idea of solving problems across disciplines. Given that these are representative of faculty across disciplines, it is clear that major obstacles remain in finding acceptance for cross-disciplinary resources. Experience with faculty evaluation committees suggests that the emphasis in universities is still very much on narrow specialization, though there is some recognition and stellar examples of people working across a range of problems.

Discussions with industry colleagues reveals that there are major dysfunctionalities in the practice of "cross-functional teams" and "Integrated Product/Process Teams". The problem is aggravated by the short span of time for which many of these teams are asked to work as teams. Typically, insecurities of the work environment and time pressures force team members to adopt the stance that they are guardians and representatives ("experts") from individual disciplines. As a result there is much less understanding across areas than there could be in a true team environment. Note that such attitudes are very different from those of many current students who work on teams: here the willingness to go across disciplines and understand issues and methods is far greater.

DISCUSSION

We have presented results from a large, ambitious and ongoing system intended to provide a comprehensive solution to various issues within the constraints of present university curricular structure. 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 needs 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 who 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 reactions, intended or otherwise, from the professional community shows a dichotomy. People show a preference to access other resources through a familiar interface. This shows the importance of developing learner-centered nodes in each particular discipline, and cross linking these. Many users are delighted to have access again to undergraduate course notes and worked examples: this is an opportunity to revisit concepts from a different perspective. On the other side, many of today's professionals and faculty are trained to believe that every job requires a specially trained expert, and hence find it very hard to understand even the concept of being able to learn and solve problems across disciplines.

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