

Learning Across Disciplines: Aerospace Digital Library

Narayanan Komerath, Marilyn J. Smith and Bethany Bodo
Georgia Institute of Technology

Abstract

The Aerospace Digital Library, <http://www.adl.gatech.edu> is a resource used by learners at all levels, to solve engineering problems by learning across disciplines. At its core is a growing body of basic technical knowledge, used by college students to explore far beyond the normal reaches of engineering courses. A learner-centered gateway, set at the level of a college freshman, links the fundamental logic of technical disciplines. A set of succinct, hyperlinked Concept Modules (CMs) form the intellectual heart of ADL, giving the learner the best of knowledge as well as information. The CMs are the hubs of ADL, providing natural starting points for knowledge searches, and natural integrators of knowledge. They open exciting avenues of DL research, and a new way of integrating technical knowledge between the classroom and the research leading edge. The beginnings of ADL are in use by students and researchers today, linking to the detailed technical content of over 70 courses across engineering and science, and to a superset of DL resources worldwide. Assessment of the impact of ADL is underway to determine its impact on both graduate and undergraduate learning. The paper describes the genesis, motivation, evolution and opportunities of ADL, including its synthesis, synergistic growth, adaptive guidance, and assessment.

I. Introduction: The Genesis of ADL

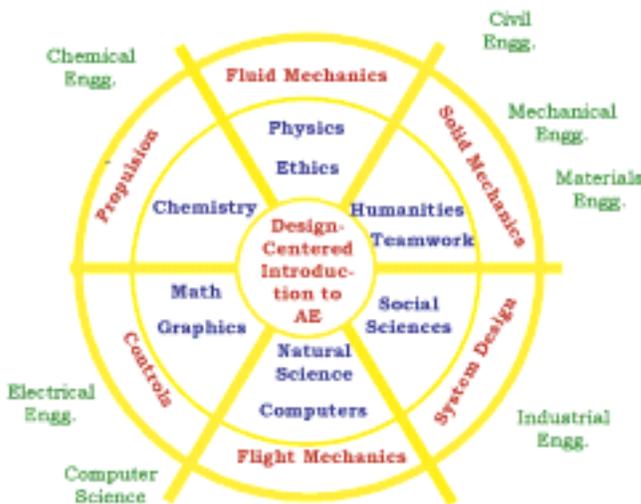
Professor Hawking¹ succinctly identifies the conflict between breadth and depth which limits curricular advancement in technical disciplines. The Aerospace Digital Library (ADL) seeks to accelerate out of this predicament. The ADL is a growing resource which *enables learners to solve problems which span many disciplines*. The DL in this context² is a resource which helps the human mind do what it does best: acquire, comprehend and condense knowledge, debate its validity, organize and save links to its



sources, identify its relevance, find it quickly and accurately, and use it to solve problems. ADL originated in the School of Aerospace Engineering (AE) at Georgia Tech, where the needs for cross-disciplinary learning, and the limitations of present systems, are keenly felt at all levels of the curriculum and research. AE is ideal for such an experiment, being rich in cross-disciplinary issues, and focused on vertical and horizontal integration of innovative systems.

Figure 1: Knowledge across disciplines is crucial to reach grand aims. Mars habitat, courtesy NASA HEDS.

Even as educators savor the success of "getting courses up on the web", and using technology in teaching, students are ahead of professors, having grown up with the internet. This is an opportunity to solve a critical problem. Contemporary engineering curricula afford too little time to grasp the evolving interactions between disciplines, *revisit* concepts, and take problems from ill-posed origin to useful



solution. Curricular compression has deepened fragmentation; few educators are comfortable in more than 2 sub-disciplines. The challenge is to create an environment where learners at all levels inquire, think and solve problems across disciplines, while preserving the rigorous discipline-specific strengths of the education system. Through a decade of experiments³⁻⁸, the ideas of "Learning by Iteration" have been proven, watching students adapt early to finding knowledge from diverse disciplines. ADL⁹ formalizes and exploits these lessons.

Figure 2: ADL's learner-centered gateway to the knowledge base.

II. ADL Structure

a. Learner-Centered Gateway

Traditionally, the beginning learner is at the periphery of the knowledge base, and the researcher/expert is at the center, delving ever deeper into the veins of knowledge. In most engineering curricula, synthesis is left to the "senior capstone design course". Various "freshmen experiences" try to provide perspective and enable synthesis, but cross-disciplinary thinking often stalls there. A primary obstacle is that undergraduates are the only people who are expected to integrate knowledge and have perspective; professors and graduate students are "specialists". ADL inverts this model, as seen in Figure 2. A design-centered introduction (DCI)⁷ is the central gateway, set at the freshman level. 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. Perspective increases, each time the learner traverses this path; the learning never stops. Similar gateways can be developed in each school, so that users can all learn subjects at the most basic level and be guided to the knowledge needed to solve problems.

b. Knowledge Base Organization

How should such a knowledge base be structured? Surely one cannot re-write all human experience! Instead, ADL constructs the means for access and guidance, and links to the efforts of others. The various levels and disciplines can be considered as in Table 1, below. This is just an example: especially in the disciplines, *many different types of organization can be considered, and different users, depending on their stated interests, may in fact be shown different kinds of organizational structures. This is one of the advantages of an internet-type resource compared to hard-copy: the same material may be linked in a totally different structure for different users.*

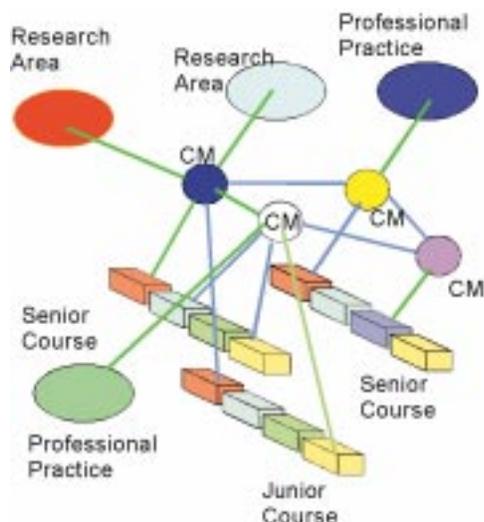
Table 1: Example of how the science/engineering knowledge base may be classified into levels, disciplines, and types of resources for access across disciplines and levels.

Number	Level 'r'	Discipline 'θ'	Type of Resource 'φ'
0	Introductory, K-12	"common sense"	Explanatory text; hyperlinks
1	College first-year	Math	Course / lecture material + fi
2	Sophomore	Physical Sciences	Numerical Example
3	Junior	Natural Sciences	Data set
4	Senior	Open	Student essay / assignment
5	Elective course	Aerospace engineering	Research Paper
6	1 st -year graduate: Masters	Mechanical engineering	Technical Report
7	2 nd -year graduate	Electrical engineering	Thesis
8	Elective graduate course	Computer engineering	Multimedia demo
9	PhD / research level	Civil & environmental engg	Concept Module
A	Open	Materials engg.	Simulation / applet
B	Open	Business	Computer program listing
C	Open	Chemical engg.	Open
open	Open	Open	Open

Thus any resource can, in principle, be assigned a unique position $[r, \theta, \phi]$ in a spherical coordinate system of knowledge, expanding from a user located at the center. Each of these coordinates, and especially the discipline coordinate θ , will be expanded to a matrix of sub-classifications. In practice, such a coordinate system should not be rigid, since the center will be at a different position for different users. Hence the coordinate system may be virtual, and may be tailored to suit the user's needs.

The lowest resource type is explanatory text and guidance, as well as hyperlinks. Beyond that, the lowest level of technical knowledge is the content of courses: these constitute our best attempt at presenting rigorous technical knowledge in a simple and logical manner. The lowest level of each course is a sequential exposition of basic knowledge (the lines of bricks in Fig. 3). Links go to "concept modules" (CMs), which are essays on specific technical subjects. CMs cover each topic thoroughly, in multiple levels. The base level is concise and lucid, perhaps at the level of an article in *Scientific American*. Links go to other courses, across disciplines and levels to imagery, examples, data, journals, debates, applications, patents etc. The CMs will combine the depth of review papers with the lucidity of classroom explanations. Layering eliminates the scientific author's paranoia about exactness versus generality in every sentence, so the CM is typically easier to read than a textbook. Within the DL architecture, the concept modules provide natural focii for search engines: this has breakthrough potential in using "information searches" to distill knowledge.

Consider an example scenario. *An engineer needs information on how to improve the stall margin of a jet engine. From ADL's DCI gateway, she goes to "Engines". The informal presentation leads to "compressors" and into the Propulsion course, with performance issues and stall margins. The CM on compressor stall leads to Instability and Control. She experiments with a controller. Back to stall alleviation, and out to technical papers, theses and prediction/control techniques, from the library. In two days of systematic learning, the engineer leapfrogs months of frustration. She knows what is "out there", up to the latest theses and conferences.*

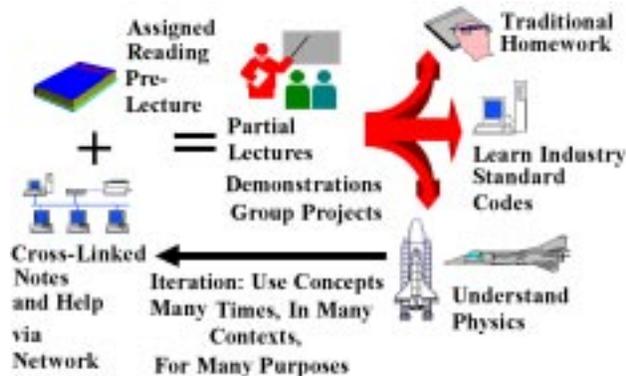


The CM-based structure, around a learner-centered gateway, is the essence of ADL. Internet resources naturally tend towards chaos. The CMs provide hubs with self-sustaining centripetal force, while individual creativity drives the knowledge envelope. They lucidly and succinctly connect technology to basic ideas. They are at the intellectual core of ADL, implementing Ernest Boyer's "Scholarship of Integration"¹⁰. A journal author and an undergraduate use the same CM to understand and relate the state of the art across disciplines. Updating CMs by generating/ indexing links can be automated through research. The lucid re-writing must be left to humans.

Figure 3: Concept Modules tie across levels and disciplines.

Creating the CMs is a challenging undertaking. The project team is writing the first of these, and then invite authorities worldwide to provide further content. As ADL expands, CMs will provide the nucleus of a peer-reviewed, integrative, publication system, reversing the trend towards fragmentation. The CMs will also tell instructors how their subject areas are evolving, and about other areas. This is the core of cross-disciplinary integration through the DL. This natural synthesis mechanism represents a potential risk, and the rationale, for ADL.

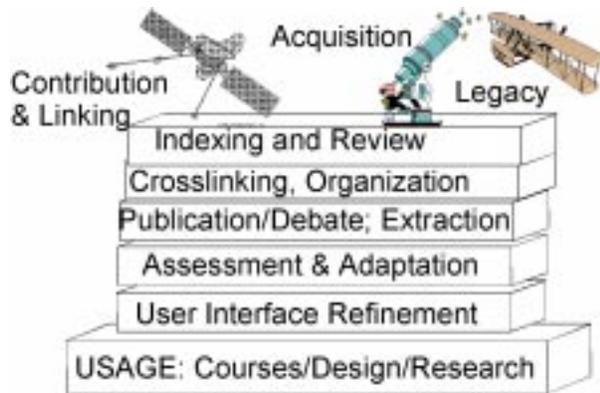
An important curricular issue is how to go beyond today's "web-based course" excitement and use the true advantages of iterative learning to solve problems across disciplines: This is illustrated in Figure 4. The AE team is integrating the curriculum into a cross-linked, multilevel knowledge base. The DCI gets learners accustomed to using information from various sources (e.g. average passenger weight on an intercontinental flight; the speed of sound near the Martian surface; how one sets up a "gas station" with liquid hydrogen; the person-hour cost of a Space Station experiment). Learners can navigate through courses to learn why and how material, configuration, and process are chosen. Links go to curricula across campus, and to industry databases, patents, and standards. Animations, videos, and simulations bring reality to students' work. Iterative learning will refine comprehension of core subjects by practical problem-solving. Inquiries from K-12 users are being directed to ADL to learn material for use in



science fair projects. ADL will cross-link the curriculum and the research world, through the Concept Modules. In turn, research advances provide motivation to refine the CMs, and thus the courses. The goal is to ensure that within four years, learners will be flying across the knowledge bases of every technical discipline, with expert guidance.

Figure 4: ADL multiplies the value of human instructors, as students link classroom learning to realistic problem-solving.

In considering the integration of ADL with the traditional library system, we use two complementary points of reference. Reference [11] is a succinct argument for balancing the drive towards technology



with a clear understanding of the values of the traditional library system, and an appreciation of the limitations of technology. References [2, 12-20] look at the Digital Library as a tool for science, mathematics, engineering and technology learning.

Figure 5: Library functions of ADL.

ADL will link to in many ways to conventional university libraries to provide:

- Seamless integration of searches across digital and analog resources:
 - Linkages across other sources of information
 - Access to other pedagogical collections such as the university Library's electronic reserves
- Digitization of content such as working papers and preprints to facilitate learning
- Interconnectivity to selected local, regional, and global information resources
- The ability to critically evaluate and filter information

III. Work To-Date

This project has followed the synthesis-first approach of Rehtin²¹. The first step was to develop enough content for students to utilize ADL in their studies and research, and to focus our thinking. The next steps are to write Concept Modules and cross-link resources. This requires an organization scheme, conducive to growth and evolution.. The process is described below:

a. *The Design-Centered Gateway*

The Design-Centered Introduction course to Aerospace Engineering was used as a means to introduce users to engineering, and provide guidance regarding the various fields. Links from this course go to advanced resources in each field. The course "notes", placed on the web, have been used in 2 iterations of the course as a central resource, and have been used by students in other courses as needed. Apart from the notes, a specific site is created during each teaching of the course for the students in the course, and this site is used for guidance to the students on finding data, notes on specific assignments, links to other course material on the web, and for students to communicate with each other and the instructor.

High-schoolers and kindergartners who contact us with questions on their science projects (e.g., how does a helicopter fly? How do I make a water melon fall faster from the top of a building?) are sometimes referred to the DCI, but in general they are much happier to be given links to official NASA research publications.

b. *Core Courses*

The full notes on the subject matter of over 70 college-level courses are now linked off the Courses Page of the ADL, (follow the Advanced Courses button from the front page of

<http://www.adl.gatech.edu> and most of these are also cross-linked from discipline-specific resource pages. It is emphasized that these are not intended as “on-line degree programs”: the idea is to have the core subject matter of each discipline given in a logical exposition. Often the courses themselves evolve much faster than ADL can, or wishes to, change this basic content. This difference is key to maintaining the open, free-access nature of ADL. Links are also provided to all open-literature sources of course content that we find on the web.

c. Digital Library Resources

The digital library resources button off the front page of <http://www.adl.gatech.edu> goes to a list of Digital Library resources, worldwide. This provides speed-of-thought access to resources as diverse as the Technical Reports Server of NASA, a library of poetry and drama, images from space, art museums, and the National Institute of Health digital resources. Several links go to authorities worldwide, such as CERN, the Louis Pasteur Institute, and the British Library.

d. Cross-Disciplinary Interface

The Resources button off <http://www.adl.gatech.edu> goes to a page of links on each technical discipline. Obviously, given our specific competence and pressures, the Technical Disciplines link under Aerospace Engineering is the most developed of these resources, but from student comments we find that they are discovering what can be found by following the links to other disciplines.

e. Concept Engines

A set of Concept Engines is being developed as the means to interconnect levels and disciplines. These are hyperlinked discussions which start at an elementary level, and go on to the leading edge of technology. Concept Engines are developed through discussions in lecture courses, based on the questions asked by, and explanations given to, current students.

f. Research-curriculum synergy

A primary aim of the ADL resource is to achieve total synergy between research, practice and curricula. This is occurring through the following means:

- a. Usage of research resources, such as descriptions of flow diagnostics and flow control techniques, in courses.
- b. Usage of explanatory course content by graduate students to learn across disciplines as needed in research.
- c. Linkage of research publications to courses make students aware of advances in a field.
- d. Linkage of professional resources such as design data and material property charts to courses so that students have access to them.
- e. Linkage to the Patent databases: several alumni have already used these.

g. Usage across levels

ADL resources usage in the following courses, is shown in Table 2. In several other courses, students have been made aware of the ADL resource, and notes have been posted, but data on student usage is not available.

Table 2: ADL usage in courses, both as Primary (P) and Supplementary (S) resource.

Course, term	P/S	Nature of Usage
Spring 98: Flow Control Senior Elective	P	Succinct notes published on ADL with figures, equations, and concepts linked as needed.
Aeroelasticity: Senior Core Course Spring 98	S	Students guided to review various ADL-based resources in aerodynamics
Introduction to AE Spring 99	P	While students had a textbook, the notes were on ADL, and students published their essays there.
Unsteady Aerodynamics F98	P	Notes on ADL, with links to review undergraduate material and research resources. Term papers published on ADL. Old tests given on ADL.
Flow Diagnostics W99	P	ADL-based notes; including technique descriptions and research resources of the AIAA Aerodynamic Measurement Technical Committee. Team reports published on the web.
Unsteady Aerodynamics F99	P	Notes on ADL; links to other material. Major assignments published on ADL
Compressible Flow Junior Core Su 99	S	ADL notes as review and support.
High Speed Aerodynamics	P	Full notes on ADL, with other course notes and research resources for review.
Introduction to AE, Fall '99	P	Students had a textbook, but full notes on ADL; assignments done by searching databases linked from ADL; airplane data and space science courses through ADL. Student work published on ADL; students contribute interesting sites that they find.
High Speed Aerodynamics, Winter 2000	P	Full notes on ADL, and all work expected to be through ADL.

In addition, graduate students entering our school now use ADL-based undergraduate course notes to review material. Students from other schools have been guided to ADL by our students to find simple expositions of such topics as Digital Signal Processing, given in application-related contexts. Alumni and faculty have started using the ADL site and provide comments as well as interesting pictures and other sites.

IV. Assessment

Assessment is being implemented in cycles of review and refinement: The assessment process contains four levels: 1. Assess progress; 2. Assess improvement targets; 3. Assess assessment techniques; and 4. Iterate.. A major part of assessment is to *examine whether the right questions are being asked and the best tools used in assessment*. The formal assessment strategy is to conduct formative surveys early, and then use the results to determine how the students are using the resources. These will be used to formulate the questions for later surveys on effectiveness.

The initial assessment of the ADL web site has been designed not only to obtain feedback from students regarding their perceptions and use of the site but also at examining student

performance in relation to site usage. Three major assessment strategies are currently being utilized. First, a short survey is being administered to the students that inquires about the students' satisfaction and use of the ADL web site. Similar forms of this survey are being administered to undergraduate and graduate students at the end of one of their Aerospace Engineering courses in the fall of 1999. In addition, these individuals will be asked to respond to a series of open-ended questions regarding the web site. Finally, in the semester following their initial interactions with the site, focus groups will be formed to address some of the critical issues that arose during the previous semester.

Assessment Results: AE 1350, Design-Centered Introduction to Aerospace Engineering, Fall 1999

Question	Response in AE1350	Response in AE6030
Extent of improvement in computer skills by using ADL	50% cited moderate improvement in computer skills due to the course; 58% cited improvement in skills with internet tools.	21.4% cited moderate improvement in computer skills; 21% cited improvement in internet skills.
ADL as help in clarifying course material	100% cited at least moderate help; 33% found it very helpful.	93% cited at least moderate help; 14% found it very helpful.
Where did you receive help most frequently?	33% cited friends; 33% cited instructor.	Only 22% needed help; all received it from friends and classmates.
Satisfaction with help received	60% found technical assistance very helpful.	Those who needed help found it very helpful.
Overall satisfaction with site	92% moderately or very satisfied.	72% very or moderately satisfied with site; 79% with the quality of the materials.
Overall satisfaction with web-assisted learning	82% moderately or very satisfied.	Question was about concept engines: 64% satisfied.

Qualitative comments: 1st semester Freshman course AE1350

- Usage in open-ended assignments: 3 of 4 respondents started to look for information in ADL, then went on to other sites from there. One started by examining past assignments in the course and then went to ADL.
- Mode of using web-based course material: One printed out the most helpful material. Another printed out only assignments, a third rarely printed anything. 3 of 5 cited going back and forth on the pages a great deal. Two found the illustrations very helpful, one remarked that reading the material was more helpful than reading textbooks, one cited the ADL material being "fast, consistent and convenient."

V. Cost-Effectiveness of ADL : Evidence from Practice

ADL is basically an open resource. There is no promise of any revenue. Thus, its economics must be justified other than by direct revenue. Three simple arguments from our experience:

1. Alumni linking to ADL course content, keep abreast of advances, and stay involved. They welcome 24-hour fingertip access to what used to be hundreds of pounds of tattered notes.
2. Researchers, worldwide, link to ADL knowledge bases and gain awareness of our past and present work, much better than from journals and conference proceedings.
3. In just one class assignment (e.g. AE2350, Spring '99), 40 freshmen looked up an average of 10 references. At \$7.40 per "reference transaction"¹¹, and an hour of hunting, the savings to the library and students are both immense. Value extrapolations are left to the reader.
4. To undergrads, ADL already appears to be a natural resource. Hallway discussions on format and content are turned into "invited contributions" and new recruits. The bottom-up expansion is happening as we postulated, as the complacent skeptics begin to feel the pressure from the students, and worry about being left behind. Having lit the fuse, we must now provide the guidance!

VI. Summary

The problem of learning across levels and disciplines is addressed by developing an internet-based knowledge resource called the Aerospace Digital Library. Access to the knowledge base is provided through a Design-Centered Introduction course, linked to several discipline areas and engineering fields. Rigorous knowledge in individual disciplines is accessed through the content of basic and advanced courses. These courses are cross-linked using Concept Modules which are essays summarizing the basics, the depth and breadth of each topic, and linking it to the many applications of that topic. Digital library resources and technical resources of various fields and disciplines connect users at all levels. The construction process of ADL, and its usage to-date, and its assessment mechanisms are discussed. The final paper will give an updated status of this long-term project, and present the results of the first year's assessment efforts. ADL is an open resource, accessed at <http://www.adl.gatech.edu>

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VIII. Biographical Sketches

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>

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 member of the AHS Fluids Technical Committee.

Bethany J. Bodo earned her Masters of Science in Industrial and Organizational Psychology from Virginia Polytechnic Institute and State University in 1996 and is currently pursuing her Ph.D. from the same institution in the same field. Currently, she is employed as the Educational Technology and Program Evaluator at Georgia Institute of Technology. This position follows a three-year graduate assistant position in the Office of Assessment at Virginia Polytechnic Institute and State University. She has co-authored and presented assessment pieces at the Virginia Assessment Group conference, the

Association for Institutional Research conference, and the Southern Association for Institutional Research conference.
