AC 2010-2255: EXTROVERT: SYSTEM FOR LEARNING ACROSS DISCIPLINES

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ABSTRACT

The EXTROVERT project builds resources to enable engineers to solve problems cutting across disciplines. The approach is to enable learners to gain confidence with the process of solving problems, starting with their own preferred learning styles as far as possible. Ideas being implemented include a design-centered portal to aerospace engineering, vertical streams of technical content, learning assignments using case studies, a library of solved problems accessible from course content, and integrative concept modules. The project experiments with assessment strategies to measure learning in time to improve it. This paper sets out the issues and builds the concept for dealing with them. The first year's progress and usage experience from Spring 2010 courses are summarized.

INTRODUCTION

This project aims to help people acquire knowledge across several disciplines and hence excel in developing new concepts. The primary focus is on cross-disciplinary learning as relevant to designing flight vehicle systems. Some development of analytical, computational and experimental learning tools for discovery and skill-building is part of the effort. The theme is to enable development of advanced concepts. Objectives are:

∝ Develop pedagogical resources that guide learning across disciplines for new concepts.
∝ Acquire systematic, transferable experience on how engineers perform in such learning.

Universities must look 10 to 40 years ahead and show what is possible to achieve. Recognizing that graduates must start contributing immediately in the workforce, learners must also be enabled to build immediately-usable skills and confidence. Our project is set in the context of the aerospace engineering program at GIT.

Aerospace engineering requires depth of understanding. Engineering recruitment in industry and government is usually based on perceived depth. Engineering curricula are designed on the reasoning that a firm foundation in basic disciplines gives the graduate a lifetime to gain breadth. Universities also try hard to "teach students to work in teams", build breadth into the curriculum and retain the interest of learners in STEM (science/ technology/engineering/mathematics) careers, without compromising on depth or rigor of specialized learning[1] or increasing time to graduation. Beyond preparatory first year courses, a course sequence going deeper into each area is the solution refined over the centuries, to turn 17-year-old freshmen into 22-year-old graduate engineers ready to work on difficult problems, with enough knowledge of methods. The intense, demanding and rigorous college experience also gives them confidence and persistence to approach tough problems.

Against this discipline-channelled tradition is today's reality of rapid technological change and short-term projects, shifting across many disciplines, nations and cultures. NASA's mandate for instance, requires engineers to be able to bring knowledge from all disciplines to bear on concepts and designs for large systems related to flight vehicles. An example is each year's NASA Reseach Announcement solicitation. The multitude of issues there would be an eye-opener to a student conditioned to think in terms of "tests in fluids, structures, controls" as the essence of aerospace engineering. NASA engineers and others trained in aerospace engineering can expect to work on most of these (and other) issues in their careers, often several projects at a time. These projects[2] push participants into regimes where there is no guidance from experience.

Today's practice is to approach large multidisciplinary projects by assembling teams with specialists in each discipline. The specialists often find it hard to appreciate and assimilate the real issues of the other specialties represented, or to articulate their own to others. This inhibits team projects, or perhaps worse, channels team projects along very rigid directions. If every specialist also had the means and confidence to learn, quickly and effectively, about the other disciplines and about opportunities in apparently unrelated fields, the team could truly benefit from the thinking of all the players, with unlimited potential for innovation.

The vision of this project is about learners with the resources and confidence to seek, grasp and assimilate concepts, methods and applications from anywhere. Central to this endeavor is for learners to gain the ability to define goals, find developments and prospects in different fields that may be relevant to these goals, and learn enough about those developments to use them in future designs. The learning system as a whole is called "EXTROVERT", symbolizing the reach towards both cross-disciplinary learning and vertical integration within disciplines for depth. Certainly the person who can talk the language of many disciplines becomes an extrovert in moving comfortably between disciplines, by training if not by instinct.

PROBLEM FORMULATION: CONTENT AND METHODS FOR CROSS-DISCIPLINE INNOVATION

Aerospace engineers must have the depth, confidence and experience to use their initiative and innovate solutions. A key feature of multidisciplinary learning is that it implies a significant amount of learner initiative to find and use concepts and material beyond those supplied by the text and instructor in a course, and the confidence to accurately use material from very different disciplines. The basic pedagogical question is: *"How should learners seek and grasp the fundamentals of new disciplines, and how 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. The intellectual challenge is to create learning environments where each team member or a lone engineer can learn efficiently about other disciplines, to formulate and develop concepts, and integrate methods into their own work.

Our project is formulated to answer the following questions:

- How will learners including those far outside aerospace engineering, gain comfortable access on their own terms to the issues and methods of aerospace problem-solving?
- How will aerospace learners gain uncompromising depth, and the experience of working with the best in the world, in what they must learn in their core areas?
- How will users learn to formulate problems from general customer needs, decide what is possible to achieve, innovate solutions and synthesize these into practical system solutions?
- What lasting products relevant to both the university and the community can be generated from this endeavour within reasonable resources?

APPROACH AND METHODOLOGY

A postulate of our work is that learning and innovating across disciplines is substantially self-driven, requiring initiative, confidence and persistence. A hypothesis driving our approach is that enabling people to learn on their own terms will enhance and sustain such initiative and confidence. The existence of different learner types is well established in the research base. What has changed is that technology coupled with our long-term investment in resource development and testing, enables us to create resources and guidance, so that *differences can be accommodated within the usual constraints of time and cost*. EXTROVERT tackles the depth problem in cross-disciplinary learning, central to aerospace projects[3]. We emphasize lifelong learning resources, available from workplace or home. Thus cross-disciplinary learning is considered at three basic levels:

- At the freshman level, reasoning that everyone is a freshman when trying to “learn the ropes” of a new discipline. Emphasis is on the “culture” and building confidence in making estimates using laws of Nature, common sense and benchmarking.
- At the senior undergraduate / new engineer level, where the emphasis is on learning to work in multidisciplinary project teams, synergizing and building off the work of others.
- At the PhD student/ faculty / senior practioner level, where the emphasis is on getting to depth in every aspect, while obtaining perspective and learning the essentials quickly.

The roots of this project started in the 1990s, as industry and government hiring and training patterns changed drastically from the large weapon-system programs of the Cold War to the small-team, multidisciplinary contract-hunting environment. The traditional curriculum had linear course sequences in different discipline streams, coming together in senior-year “capstone” design experiences. During the Cold War era, large-company recruiting emphasized corporate training after school. To prepare students for the small-team environment that came up in the 1990s, we moved towards increasing comprehension levels, and enabling students to gain experience and perspective through research participation and other learning by iteration.

Learning Through the Conceptual Design Process

As research material grew on the internet, it became possible to provide an organized portal to such knowledge. In 1997, we tried using Conceptual Design of flight vehicles[4] to engage freshmen in their first week of college *(“in 6 weeks you will be testing your own airplane design”),* and introduce aerospace engineering. Students responded beyond all expectations to the opportunity to use their innovative spirit and curiosity across disciplines. Success over 3 years[5] and now 12 years, has debunked the superstition that all Design study had to be left to the senior year. Soon, team design courses were pulling freshmen into Design-Build-Fly, and space concept designs.

Guided Portal to In-depth Aerospace Courses

In 1998, we turned the Design-Centered Introduction into a web-based portal, putting the entire course notes on the web as an introduction proven to work with learners at the high-school graduate level. This was followed by web-based versions of several other courses as the building blocks for a cross-discipline knowledge base, plus links to web-based curricular resources elsewhere. This Aerospace Digital Library (http://www.adl.gatech.edu) resource based on principles from the Digital Library field, has helped a generation of students learn to solve problems across disciplines naturally from the freshman level onwards[6,7,8,9,10]. The learner-centered gateway links the fundamental logic of technical disciplines to the leading edge of technology in several disciplines. As reported at the NASA Workshop in 2003[11], since 1998, this resource has operated with less than 2 days of total down time, and has seen use by students in numerous courses. Despite heavy use by our own students in courses, we found in 2001 that over 70 % of the usage was coming from outside the Institute.

In the 1990s we experimented with the notion of technology-intensive (neural network based) intelligent adaptive interfaces to guide learners to different types of materials. However, the revolutionary advances in Search Engine technology, and the rapid rise of user comfort with the idea of having to sift through large numbers of links, made such complex schemes irrelevant.

Design Team Experiences

In recent times, design team experiences have become accessible at all levels, including “Design-build-fly”, “RASCAL”, and other projects that include freshmen through PhDs. Research project participation as paid assistants or in “Special Problem” courses for credit, and collaborative team experiences such as “Reduced Gravity Student Flight Opportunity” and “NASA Means Business” are increasingly seen. These complement experiences as Interns or Co-Ops.

Multidisciplinary Systems Design and Optimization

Since the early 1990s, the Aerospace Systems Design Laboratory at Georgia Tech has developed into one of the world’s largest university resources for multidisciplinary system design studies. Learners working here range from freshmen to graduate students, post-doctoral fellows, research engineers and faculty. They work on a large number of problems from various government and industry sponsors, and have organized themselves into an environment where team members at all levels can be integrated into teams. A range of analytical tools and standard operating procedures have been developed, that are available for use in courses. Thus we now have the following formal resources as a starting point for the project:

1. An extensive set of in-depth curricular resources on the internet, with a demonstrated 12-year record of reliable access for use in aerospace engineering courses.
2. A proven gateway to introduce learners to aerospace engineering starting at the high school level but connected to resources going all the way to the doctoral level. This has been proven to be usable by students at the entering freshman level for the past ten years.
3. Extensive experience of involving students in research projects and in multidisciplinary design optimization tasks.

Adapting Learning Resources to Learning Styles

How can one engage the learner and build confidence, so that the learner takes the lead? This requires that learners make themselves comfortable and find it possible to learn through the types of resources that they prefer. There is wide disparity between individuals as seen in studies of U.S. Air Force pilots[12], for instance. Felder[13] and Silverman[14] cite the mismatch between learning and teaching styles commonly found in engineering school, and showed that teachers tend to focus on their own learning type since it was successful for them. Keri[15] and others[16] showed that academic success correlated with matching between students' and teachers' styles. Faculty can typically teach to only a fraction of the learning styles of students, within time and resource constraints. Our solution is to allow each student to start learning through the resources that they find most natural, and then adapt gradually to other styles.

We studied the Learner Types set out by education psychologists, and developed a classification applicable to our students. These are related to the traditional definitions of types of intelligence. User-level definitions of these types are given below:

The Barnstormer is eager to experiment, learning by trial and error. Too impatient with lengthy "derivations" to obtain elegant solutions, s(he) learns as needed and works intensely on a deadline. S(he) launches bold experiments, and ventures into the unknown with little hesitation.

The Eagle: A separate category must be devoted to those who must have an eagle's eye view of what they are being taught, before they can focus. Long derivations lose them. These are the people who can rise above the details and see the "big picture", and make brilliant connections across vast gulfs between disciplines. They are potentially entrepreneurs. Once convinced, their belief is unshakeable.

The Rocket Scientist too will venture into the unknown, but with rigorous analysis. S(he) takes nothing for granted, and wants everything tied to first principles, with uncompromising, rigorous derivations based on the laws of physics. S(he) is usually strong and deeply interested in applied mathematics and physics.

The Astronaut is very focused and mission-oriented. Far from being the rash adventurer of popular lore, the Astronaut's real strength is discipline, reliability and excellence in following procedures rigorously with a clear mind even under the most stressful of conditions. S(he) wants detailed instructions and training, and lots of worked examples.

Facilitating Group Learning

A short-term objective is to allow cross-discipline project teams to use their brains and time effectively towards a common purpose. Engestroem et al[17] studied the vertical and horizontal dimensions in the development of expertise, analyzing cases of collaborative problem solving and learning 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. Springer[18] argued for more widespread implementation of *small-group learning* in college SMET curricula. In our research[19] and in research at other institutions, *active learning* involving the web has been researched using individual classes. We have a large cumulative bank of experience on how students learn and knowledge is transferred in research groups.

RESOURCE STRUCTURE

The primary customers are defined as
1. Present GIT aerospace students
2. GIT AE alumni
3. NASA and industry new employees getting oriented
4. Engineers refreshing pre-requisites for Distance Learning graduate school
5. GIT AE graduate students taking courses across technical disciplines
6. Graduate students preparing for PhD Qualifying Examination
7. NASA and industry experienced engineers working on new proposals/ projects
8. Cross-disciplinary project teams

EXTROVERT Gateway

As planned, the first two years of the project are devoted to intense resource development, while the final year will be devoted to user and peer assessment, refinement and publication. A basic structure to facilitate content addition and user experience has been designed and implemented. The EXTROVERT gateway serves as the portal to the entire resource. The site provides access to all of the content in the pre-existing Aerospace Digital Library, the content of which is being updated, reorganized and significantly expanded as a part of EXTROVERT. The gateway is at present at rudimentary functional form, as we consider different designs for its first public-release appearance.

Design Centered Introduction

At the core of EXTROVERT is the notion of that all resources should be accessible, with a choice of navigation paths based on individual preference, from a centroid where all sub-discipline areas coalesce. The interface must empower the learner with the knowledge and skills necessary for the conceptual design of aerospace vehicles. This Design-Centered Introduction, after testing and refinement over the past decade, has now been distilled into a sequence of short modules. Optimization of different mechanisms to efficiently engage learners with this material is being explored. Refined module sets in incompressible and compressible fluid mechanics and aerodynamics, including transonic and hypersonic theory and methods; jet, rocket and space propulsion; composite structures; and rigid and flexible body (structural) dynamics, are expected to be incorporated into the new web-based learning modules.

McMahon Solutions Library

The single most important resource needed to implement EXTROVERT is a library of solved example problems and applications to guide learners. This effort has made significant progress, incorporating and converting to electronic form a large solved problem set resources dealing with fluid mechanics, aerodynamics, gas dynamics and propulsion. The core of this comes by kind permission from the estate of the late Professor Howard M. McMahon, who developed a large set of solved examples and test questions over his 34-year career at our school. The McMahon Solutions Library now enables learners to navigate worked examples at a wide variety of skill levels in these core areas. A basic structure is in place and is being utilized in academic courses and PhD Qualifying Exam preparation. These experiences will guide expansion to other disciplinary content across the aerospace curriculum.

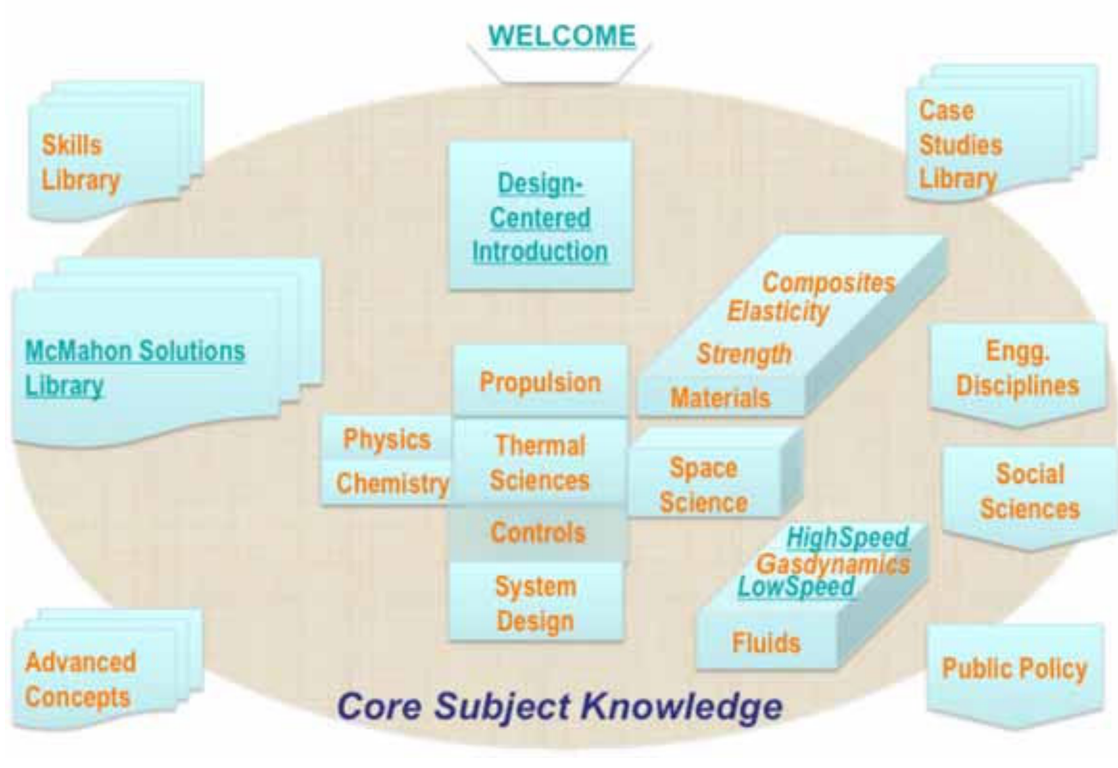

Figure 1: Resource structure for core subject knowledge

A Case Study Approach to Aerospace Engineering Instruction

The case method is a pedagogical approach that is employed in the social sciences, medicine, and most commonly, business management[20]. This aspect of the project is discussed in detail in a companion publication at this conference[21], so we will limit discussion of it here. Two large case studies in aerospace systems have been developed. A study of the C-5 transport aircraft project is discussed in the companion paper mentioned before. The case study in this context is much more than a historical discussion. It includes in-depth calculation modules and simulations on various aspects of the project, with the project itself serving as the integrator of all the different illustrations. A second case study on the Space Shuttle transportation system is being developed.

Advanced Concept Development

The third challenge (beyond engagement and breadth) is to get learners to exercise what they learn, in developing innovative solutions to ill-specified problems, going well outside textbook knowledge and traditional methods. Hargaddon[22] argues that this process depends on the presence of networks, of dynamic interaction between people in different fields of endeavor, and "working in a number of outside worlds". It also comes from a culture of constantly thinking across, rather than just along, traditional disciplines. We are attempting to implement a model that picks aspects of the NASA Institute of Advanced Concepts[23,24], whose projects involved students at the graduate and undergraduate levels, including our own[25,26,27,28]. Another endeavour is to show how risk assessment and reliability engineering are brought into the evaluation of advanced system concepts[29,30] and the rationale for on-orbit repair[31,] and maintenance systems.

The first of our full-scale advanced concept explorations is a renewed look at the prospects for supersonic hydrogen-fueled airliners. This multi-disciplinary exercise has been pursued by student teams at freshman, senior and research team levels, and an experience base is being refined from this project. A companion paper at this conference[32] describes that experience. The work has progressed at this writing to a poster presentation by a team consisting of two sophomores and two seniors – the sophomores bringing their experience of conceptual design and carbon market business case development from the freshman introduction course, and the seniors bringing their experience of supersonic aerodynamics from a core course in high speed aerodynamics, besides their experience from the Vehicle Performance and Aircraft Design courses. Other involving graduate student teams deal with the design of a lunar cargo system, and of a Mars surface-orbit shuttle. These are being refined from course experiences.

Skills Library

A Skills library is being accumulated, where learners can access sophisticated tools. Examples are the Wolfram Mathematica Online Solver, various aerodynamics codes for finite wings, panel methods, coupled panel/boundary layer methods, transonic small disturbance solvers, shock-expansion applets and other codes. Simpler but frequently useful resources such as an atmosphere calculator a unit converter, aviation weather forecasts, the Periodic Table, and materials properties round out the library.

Technical Module Design

Once a learner enters a technical module, the ability to move between learning material should be easy and transparent. The "Notebook" concept includes easy access across both disciplines and learning material. Longer segments are covered in sequential pages. Tabs and a table of contents permit rapid exploration. Technical terms have roll-over definition and links to their theory pages. Worked examples, intuitive learning demos, papers, case studies, etc. are made available via tabs. This format aims to provide clean, streamlined access. We are moving to "wiki-like" author insertion to facilitate addition of new material. Each module has a self-contained assessment section which also links to the web-based assessment surveys discussed later. The page design is being iterated with student learners to understand preferences and ensure functionality.

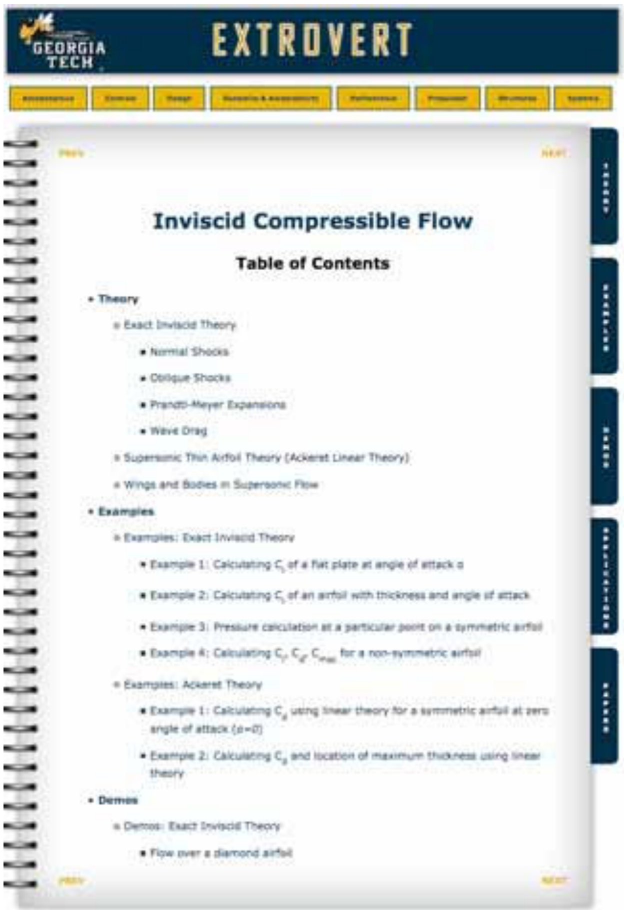

Figure 2: Contents page of a technical module on inviscid compressible flow, suitable for undergraduate and graduate learners in high speed aerodynamics

E-book formats

One interesting development is that NASA has ventured into the "e-book" format with the release of an e-book on the X-15 project[33]. This is a fast-evolving technology. With the Sony PRS readers able to read standard pdf documents, this process has become much easier. As color comes to Personal Readers with the advent of the Apple ipad, we expect that more sophisticated documents (and cooler color pictures) can be published in e-book format. This may become a good means for knowledge transfer from industry experts to the next generation of engineers.

Assessment Strategies

Our assessment strategies are born of over 50 person-years of experience with large and small classes, and recent focused usage data with diverse learner populations. A prototype of a module-based learning assessment tool has been tried out, using the "Survey Monkey" web-based tool. Modular learning assessment, as the name implies, ties the assessment to individual learning modules rather than the entire courses. Such assessment enables the learner and the teacher to quickly review learning effectiveness, in time to improve learning. The survey modules are tied into web-based resource, a convenient way to address the IRB requirements with minimal intrusion into the learning process.

3. How did you learn and do the assignment?

	Very little	A little	Somwhat true	Mostly true
Knew the stuff from undergraduate classes, no sweat				
Prescribed textbook(s)				
EXTROVERT Notes for AE3021/ undergrad aserodynamics				
Classroom lectures and discussions				
Asking others				
Other textbooks				

Figure 3: Assessment prototype used for one specific assignment, using the web resources at http://www.surveymonkey.com

1. Module 1: Introduction, Supersonic Airfoil, and Assignment 1 (everything before Transonic Flow)

Modular Learning Assessment, 1: Introduction

Learners can use this to reflect on what and how they learned, and what proved difficult, and what resources they used in learning. You can enter more than one answer on each question.

Add Question Here

Edit Question | Move | Copy | Delete

1. Please rate the level of difficulty, how well you knew the topic before, and how well you now know the topic

	Completely lost	Asked someone for help to get started	Looked up text & notes	Makes sense now	Knew it all before
Low Speed Aerodynamics Review					
Compressible Flow Review					
Full Potential Equation					
Linearized Potential Equation					
Similarity Relations					

Figure 4: Example of modular assessment for a set of lectures covering roughly two weeks, in this case a review of prerequisite work in graduate high speed aerodynamics.

CONCLUSIONS

The EXTROVERT project is a bold attempt to deal with the issues of learning across disciplines in order to turn advanced concepts into reality. It is founded on the core knowledge of aerospace science and engineering, but uses a Conceptual Design gateway to make this knowledge quickly accessible and usable. Intense effort to develop a library of worked examples is a key feature in opening the knowledge base to different types of learners. At this writing, the initial test website is up with a substantial amount of core content, and a number of resource modules and case studies are being refined and uploaded. Full-scale usage and assessment are scheduled to start in January 2010 with the Spring 2010 semester.

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