EXTROVERT: Experience with Cross-Disciplinary Learning

ABSTRACT

The EXTROVERT project builds resources to enable engineers to solve problems cutting across disciplines. The theme is to enable development of advanced concepts. The approach is to enable learners to gain confidence with the process of solving problems, starting with their own preferred learning styles and in their own home disciplines 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. Experience from six areas is summarized. Case studies are used in class assignments for detailed analysis. Advanced concept development projects are used, involving students at all levels in classes and research, to provide guidance on how to proceed with innovation in the face of large uncertainty and skepticism. These include concepts for a hydrogen fueled supersonic transport architecture, power beaming for a Space-based exchange and retail power delivery, and testbeds for renewable energy systems. Finally, interdisciplinary courses at the senior undergraduate level mesh learning across several subdiscipline and disciplinary areas. Initial samples of formative assessment data reveal the learning style preferences and problem-solving approaches of current engineering students as they deal with the availability of diverse resources. Transferable lessons on the various issues in cross-disciplinary learning are distilled from these experiences.

INTRODUCTION

The EXTROVERT [1] project is a bold attempt to deal with the issues of learning across disciplines in order to turn advanced concepts into reality. The need to deal with such issues is recognized in engineering practice [2], though building breadth into curricula while retaining depth has been difficult [3]. Our project is a prototype for cross-disciplinary learning resources. Rather than try to build cross-disciplinary projects into courses, we invert the problem and focus on creating lasting resources that can be accessed and used by people outside the confines of each course. In fact we intend for these resources to be used by engineers long after they leave college, and view the college part of the experience as something to test the hypotheses and refine the resources, build the culture of learning what one needs to innovate.

The project is founded on the core knowledge of science and engineering in each discipline, but designed to facilitate productive access by people from outside specific discipline areas. It uses a Conceptual Design gateway and a set of Concept Essays with their thresholds set at generalist levels to make this knowledge quickly accessible and usable. Continuing development of a library of worked examples is a key feature in opening the knowledge base to different types of learners. The idea of providing examples is extended to larger problems. In-depth case studies allow learners to delve into the development of famous flight vehicle designs, doing the calculations behind critical decisions. Advanced concept development exercises illustrate how one performs initial explorations of feasibility on systems that may be 30 years away, and then reduces uncertainty in the estimates. Lessons contained in student
efforts to conduct short-term projects are also included. An initial paper in the 2010 conference [4] set out the issues and built the concept for dealing with them. The first year’s progress and usage experience from Spring 2010 courses were summarized. At this writing, a second iteration of the test website has been developed, with password-controlled access used to trace learners’ progress and learning style preferences as they navigate the multiple levels of resources. The present paper summarizes efforts in each area, and then addresses the issues in learning across disciplines.

EVOLUTION OF THE EXTROVERT IDEA

The idea for this project developed in the 1990s through a series of experiments on improving learning, first focusing on experiential learning [5], and then on vertical integration of curricula to facilitate several iterations in learning within the constraints of the typical engineering curriculum [6]. Proposals to the National Science Foundation in the late 90s envisaged the development of resources encompassing and integrating aerospace engineering disciplines, and using internet technology as appropriate. This was conceptually adapted and expanded to cross-disciplinary problem solving. A pilot website known as the Aerospace Digital Library (ADL) [7,8], has remained in continuous operation for over 12 years with recent usage averaging over 12,000 hits daily by learners from around the globe. This resource enabled technical experiments [9] and ambitious concept-development efforts for a generation of students who now take such resources for granted. This showed that engineering students can indeed venture well outside their home disciplines to solve problems, learning what they need from other disciplines.

At the same time, several serious issues demanded attention before cross-disciplinary learning and problem-solving could become routine. The first is the depth required for engineering problem-solving. The second and probably more difficult issue is that the present generation of faculty came up for the most part through a system that emphasizes specialization, and they tend to frown on efforts by people from “outside” their discipline to use knowledge from their disciplines. Symptoms of insecurities are evident from anecdotal descriptions of industry and government “cross-functional teams” of experts. In the decade since the ADL was set up, search engine technology and the use of on-line resources blossomed. Disparate learning styles became apparent when students gained access to multiple resources through the ADL and similar resources. Students in the same class reacted in diametrically opposite affinities to various types and orders of presentation of the curriculum. Some loved in-depth, rigorous course material with backup derivations, logic and argument, provided on-line. Others hated that and preferred a quick overview, while still others went straight to old test questions and solved problems. Some wanted graphical resources and colorful animations that showed real fluid and system behavior, while others proclaimed those to be a complete and irritating waste of time and bandwidth, suitable only for children. In proposals to the NSF in the early 2000s and in subsequent papers in the ASEE proceedings, we conceptualized and tested how to cater to different learning styles. The next step was obviously to take the ADL resources to the a level, where resources could be tailored to help in addressing the above issues.

Certainly, there is a substantial and fast-growing body of literature on the issues in learning across disciplines. Beasley et al [10] considered detailed processes for curriculum design. They listed several integrative experiences that would bring together diverse parts of the curriculum in
an engineering department. Carlson et al [11] viewed Design-Build-Test project cycles as an excellent means of cross-disciplinary innovation and knowledge transfer. Kleppe [12] describes a multidisciplinary capstone design course for high school teachers, bringing together various aspects of innovation and entrepreneurship. Kostoff [13] looked at developing processes for enhancing innovation, by transferring information and insights between disciplines that were unlikely to acquire these insights otherwise. A hybrid approach combining literature searches and workshops was found to work best in the case of developing autonomous flying systems. However, this was also found to require very substantial resources. Clouse et al [14] describes a Workshop where faculty from diverse disciplines ranging from arts to atomic physics, engineering and law, infuse entrepreneurship concepts in their courses and share syllabi, in order to promote entrepreneurship.

Obvious resources used by students (and their instructors and industry colleagues) include the various web-based Encyclopedia sites such as Wikipedia, and the tremendous capabilities of Search Engines when combined with the curious and lateral-thinking brain. In many ways, “speed-of-thought access from anywhere on the planet or even beyond”, dreamt of in the 1980s by engineers surrounded by bookshelves full of “I know it’s there somewhere” resources, has now become a reality. Sifting through the millions of links provided by such searches, while far easier than once feared, still poses problems. The concern about unreliable information is real, but for the most part, people recognize the need to form independent judgments based on multiple answers to the same question. In other words, the need for quality is still paramount, and has become even more important, but should not detract from the freedom to explore knowledge resources. On the other hand, online journals have proliferated, and make on-line basic knowledge all the more important and relevant to use such sophisticated resources.

**LEARNING RESOURCES**

A basic structure to facilitate content addition and user experience has been designed and implemented as shown in Figure 1. At the core of EXTROVERT is the notion of that all resources should be accessible from a centroid where all subdiscipline areas coalesce. The EXTROVERT Gateway [15] serves as the portal, centered on aerospace engineering. 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 interface in the case of aerospace engineering is set in the conceptual design...
of aerospace vehicles, a theme that gives the learner a quick perspective of all disciplines. This Design-Centered Introduction, after testing and refinement over the past decade [16,17], has now been distilled into a sequence of short modules. A new template reminiscent of a book format integrates several types of resources such as course notes (the vertical stream of basic knowledge), solved examples for formative assessment, calculator applets and downloadable codes for problem-solving, and technical papers to go further in depth. 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 incorporated into the new web-based learning modules.

**COURSE EXPERIENCE**

In the sophomore low speed aerodynamics course, students enthusiastically used the library of solved problems, as well as old tests supplied by the instructor, in their formative assessments. Student preparation to use technical tools such as MatLab was significantly better than in prior years. In high speed aerodynamics, the availability of such resources made it possible to give students the ability to review prior course material, and refresh problem-solving experience. This had the surprising effect of allowing the instructor to expose areas where students needed better comprehension. It also denied many students the comfort zone of not going outside the immediate material of the present course. As the semester progressed, students started coming “alive”, showing a remarkable level of enthusiasm and attention for required core courses. During the initial semester when the solved problem library was first available, the students in graduate high speed aerodynamics had not reconciled to the need to use the resources, and this reluctance to use the resources is seen in the present (Spring 2011) semester as well. We are beginning to realize that there is a substantial cultural resistance in students from some other universities, to the idea of learning in a different manner from what they used in the past.

One of the most difficult courses, as cited by undergraduate student experience, is the senior aeroelasticity and structural dynamics course. This course requires that students assimilate three different subdiscipline areas (fluid mechanics, structural mechanics and controls), along with rigorous mathematical application. A common thread among student commentary is the need to recall information that was last studied two or three years prior to the course. The EXTROVERT template has been utilized to provide concise introduction of specific technical material with links to applicable topics in the different discipline areas. These are augmented by worked problems that illustrate the mathematical principles necessary to resolve engineering problems of interest. Finally, structural dynamic and aeroelastic cases from current and historic applications (e.g., Tacoma Narrows Bridge, wind tunnel model failures) provide feedback to the students of the importance of the topic. In prior semesters, data has been gathered to identify the weak points of student understanding of this material.

**Case Study Experience In Courses**

Two large case studies in aerospace systems have been developed. These are intended for use in course assignments, where students can be asked to go in technical depth into specific aspects while gaining perspective on the role of that aspect in the overall case. One is on the development of the Lockheed C-5 transport aircraft. This study includes MatLab computation
modules and data sets. It has been classroom-tested and is available in the EXTROVERT system. Results from course usage were reported at the ASEE 2010 national conference [18]. A case study on the Lockheed SR-71 supersonic high altitude reconnaissance aircraft has also been completed. A third case study is on ferrying the Space Shuttle Orbiter vehicle across the continental USA using a Boeing 747 aircraft. This STS Ferry case study has undergone one round of undergraduate course testing with excellent results.

Advanced Concept Development
Concepts being developed include a supersonic airliner fueled by liquid hydrogen [19], a business case for a micro renewable energy systems architecture [20], a concept for terrestrial solar power exchange [21], one for a photoelectric/photovoltaic power converter for kitchens, and one for retail power beaming to villages [22]. These concept development exercises are intended to provide experience on the thought processes and estimation techniques that allow an engineer to go from a desire to solve a grand challenge problem, to define the problem statement, and systematically reduce the uncertainty bounds until a set of 2 or 3 viable choices are refined, for tradeoff against each other. The uncertainty-reduction aspects go into depth in technical courses, whereas the process of obtaining initial estimates draws on basic laws of science, and ‘common sense’.

ASSESSMENT OF OTHER ASPECTS
Various means are being used to learn how learners respond to the new resources. With Institutional Review Board (IRB) approval, students are asked to use anonymous survey resources at an independent website, starting with assessments of their own learning practices and use of specific resources. Specific formative assessments are used with each learning module (typically a one or two week set of lecture notes). Summative assessments are provided through old question papers, and through a randomized “Things You Should Know By Now or Find Out Right Away” list of short questions. The solved problem library, though quite sparse at present, is proving to be a much-used resource, with the unusual sight of undergraduates finding errors arising from mistyped or missing steps and numbers.

The initial response from students taking required courses is that the posted class notes are the primary resources used by students, followed by the textbook, notes posted on-line by other instructors in our institution or at other institutions, the old tests provided by instructors, and the solved problem library. These results are discussed at greater length in a companion paper submitted to this conference in the Aerospace Division, since the results are at present from AE courses alone.

Figure 2: Knowledge base structure with concept modules providing the transfer points.
CROSS-DISCIPLINARY LEARNING

A key idea in implementing the resources for cross-disciplinary learning, is that of “Concept Essays” or Concept Modules (CM). These are succinct summaries of given concepts, that bring together the definition, basic concept description, a summary of theoretical and empirical approaches, and examples of several application areas, into an essay, nominally aimed at a 5000-word size. These are viewed as the gateways to, and the “junction boxes” between, different vertical streams of specialized technical content as shown in Figure 2. One does not become competent by stopping at the Concept Essay, but going back and forth between concept essay, notes, worked examples, technical papers and other resources, enables determined innovators to get a sound footing for their innovations drawing on multiple disciplines.

The Design-Centered Introduction course, the Advanced Concept exercises and testbed developments provide the best glimpses of cross-discipline learning to-date. With guidance, freshmen enthusiastically range across disciplines, find and evaluate knowledge from anywhere, mostly using the internet. For instance, they had no difficulty with incorporating Carbon Market information into their conceptual designs. In upper division classes, students are generally focused on their home discipline, and increasingly fearful of going to other disciplines. The concept development exercises, especially when set in the context of prior work by undergraduates at the same or other institutions, induces ventures to the hardcopy library and into professional papers and reports. Obviously there are problems with capturing more than basic conclusions from such papers.

The presence of such a resource exposes some deep flaws as well as excellent opportunities in present curricula, and in the level of student preparation and standards of comprehension. Students often attempt to avoid going back and gaining deeper understanding of prior courses, confident that instructors do not have the time to present material beyond the present course. By providing problem-solving resources and guidance, this weakness in the depth of learning is removed. Students adapt to the resources, and gain in depth of understanding and breadth of knowledge. Resistance to the idea of learning “theory” and logical mathematical derivations, as identified through formative and summative evaluations in our courses, appears to be a prime inhibitor to attain full breadth and depth of understanding of complex material. Instructional techniques that have succeeded in inducing this change in attitude are discussed in the paper. Despite the complexity of the core content, most students do very well in concept innovation when provided some guidance.

With the aerospace core development in full swing, the remaining issue in this paper is how to transfer the aerospace template to other disciplines, so that the cross-linking in Figure 2 is extended across the knowledge base, spanning numerous disciplines. Figure 3 illustrates our initial concept in how an engineering learner (in this case in aerospace engineering) views the outside world.
The role of the design-centered portal is to enable the learner to come “up to speed” rapidly and through a systematic process. One issue that is being worked on, and will be reported in the final paper, is to define corresponding portal descriptions that might be suitable for each of several other disciplines. The conceptual design exercise used in the AE portal may be replaced in chemical engineering with a top-level description of how a chemical plant is planned and designed, and its lifecycle. The “DSP First” initiative in the 1990s pursued an introduction to the field of electrical engineering[23] through the avenue of digital signal processing, whose end-user applications and power are familiar to most college students. We hope that this paper leads to a discussion among readers in the ASEE’s multidisciplinary division, on the appropriate portal design unique to each discipline.

The learner must have some organized scheme for accessing this bewildering array of resources needed to understand engineering and solve problems. One way in which we are approaching the construction of resources for the cross-disciplinary learner is through web pages that resemble electronic books. This is illustrated in Figure 4.

**DISCUSSION**

Some comments on specific items are relevant here to convey a sense of what these new resources bring to the experience and repertoire of the users.

1. **Case Study experience with the STS Ferry case.**

   “(Students (in the AE3310 Vehicle Performance course) just finished the Shuttle Heading Alignment Circle (HCA) and Shuttle Carrier Aircraft (modified 747-100) study. The instructor) gave them data and limited instructions (kept this one more open-ended), and many of the students did superb projects!! Very pleasantly surprised. They had to compare/contrast the 747 performance with and without the Shuttle in carriage. I provided real drag polars (wind tunnel data) from the NASA NTRS site, real engine decks (thrust and fuel flow as functions of Mach, altitude, and power lever setting) for the Pratt and Whitney
JT9D-7F engines, and weights statements. Using this data and MATLAB codes that they had to modify substantially, they plotted drag polars, engine power hooks, and drag and thrust available vs. velocity curves, computed maximum velocity and maximum climb rate as a function of altitude, and determined the payload-range diagram envelope. They did this with numerical root finding algorithms using the real tabular data instead of the highly simplified analytical expressions that they use on their exams (2-parameter quadratic drag polar without Mach/Reynolds effects, "max thrust is constant with velocity, etc."). All the analysis was done both with/without the Shuttle and the impact on performance with the Shuttle is very noticeable!!”

2. Advanced Concept Development: LH2 SST

“In AE3021, High Speed Aerodynamics, students were given 5 hours of lecture on the prerequisite low speed aerodynamics, thermodynamics and gas dynamics courses, with both the condensed survey of results and the detailed course notes available online. The resulting expectation that they must be able to solve problems encompassing low speed and high speed concepts, proved to be quite a shock to several students, who appeared to be used to the guarantee of strict narrow compartmentalization in each course. On the other hand, several students really “took off” in comprehension and competence. The assignments in this course rapidly built up capabilities. For instance, students had to develop their own “calculators” based on spreadsheets and Matlab coding, for Prandtl-Meyer expansions, critical Mach number, normal shocks and oblique shocks, instead of being dependent on textbook tables or internet-based applets of dubious provenance.

An introductory lecture on the notion of re-examining the prospects for supersonic airliners used the technical paper developed and published by undergraduate team efforts under EXTROVERT. The class was asked to take up this paper in teams of two, re-work the conceptual design calculations, and then attempt to refine the predicted lift-to-drag ratio and seat mile costs, to decrease uncertainty.

This assignment empowered students to come up to the leading edge of research on supersonic wave drag prediction, with many teams examining both classical and very recent NASA work on this topic. Innovative solutions from the course are being incorporated into the next publications on this topic, with the students invited to co-author.

Overall, the level of excellence and maturity of the top 30 percent of the class, far exceeded what we had been able to achieve at the junior/senior level in aerodynamics by a wide margin. On the other hand, students who simply did not use the provided resources, did find themselves getting left behind.”

3. Solutions Library

“In low speed aerodynamics (AE2020) students showed keen interest in using the McMahon Solutions Library and the provided survey questions to help improve their problem-solving and thinking abilities.”
CONCLUSIONS

The EXTROVERT cross-disciplinary problem solving resource, at the end of its second year of development, is summarized. Built on an aerospace engineering core, the resource aims to facilitate innovation by providing a sound footing in the different parts of the learners’ core discipline and then using the examples and links from advanced concepts and case studies to venture into other disciplines. Specific conclusions are:

1. A portal to the major discipline set in conceptual design enables learners starting at a high school level to obtain a quick and useful perspective, as well as entry to in-depth resources.
2. Vertical streams of content are integrated from notes used in courses across all levels of specific disciplines.
3. Concept essays and concept modules provide succinct introductions to the detailed vertical streams of content.
4. A living library of worked examples caters to learners who start with that as their mode of initial learning, and to those who use these solved problems as formative assessment of course modules.
5. Case studies and “real world” applications provide perspective and in-depth engineering analysis experience to motivate learners and stimulate depth in thinking processes.
6. Advanced concept explorations help learners build “common sense” estimation skills based on the laws of science, and experience with the process of systematically reducing uncertainty and identifying areas requiring more knowledge while refining concepts.
7. Initial learner reactions to the new resources, being expanded to include results in the upcoming Spring 2011 semester, identify the current preferences of undergraduate student learning practices, placing the course notes and textbooks at the top of their preferences, followed by old tests and worked examples.

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REFERENCES

[1] To answer a reviewer’s question: EXTROVERT is a name, spelled in all caps. It may suggest the characteristic of going out of one’s way to communicate and work with others.