Session 2793

PROACTIVE TEACHING AND LEARNING IN THE AEROSPACE ENGINEERING CURRICULUM 2000

Brian M. Argrow
Department of Aerospace Engineering Sciences
University of Colorado
Boulder, Colorado 80303-0429

Abstract

The inception of the Aerospace Engineering Sciences, Aerospace Engineering Curriculum 2000 provided a unique opportunity to introduce the ProActive Philosophy for Teaching and Learning. The curriculum was reformed both in content and teaching methods. It shifted emphasis from compartmentalized basic science, mathematics, and engineering science courses to those designed to integrate topics, provide hands-on experiential learning, and a renewed focus on product design. The new curriculum employs the resources of the Integrated Teaching and Learning Laboratory to incorporate a hands-on component for core undergraduate courses. The ProActive Teaching and Learning Philosophy was implemented with the new curriculum. This philosophy enforces student preparation and capitalizes upon this preparation to replace the conventional, passive lecture with an interactive session in which all students actively participate in topical discussions. In addition, team teaching is now the standard in the sophomore and junior courses.

Introduction

The ProActive Philosophy for Teaching and Learning was introduced with the Aerospace Curriculum 2000 (AE 2000), in the fall of 1997. The new curriculum for the Department of Aerospace Engineering Sciences (AES) was reformed in content and a new teaching and learning paradigm was introduced. Course content reform primarily focused on horizontal integration of the engineering sciences, hands-on experiments, and design in a teaming environment. There is a renewed emphasis on the implicitness of computing and communications. The MATLAB programming environment is incorporated into most courses and writing and presentation skills are emphasized. The Integrated Teaching and Learning Laboratory (ITLL) made the reforms realizable.[2] Seebass and Peterson

AE 2000, midway through year five. The sophomore course ASEN 2002 Introduction to Thermodynamics and Aerodynamics is discussed in detail to illustrate horizontal integration, hands-on experiments, design projects, and implementation of the proactive philosophy. Finally, challenges and compromises in maintaining the AE 2000 are discussed.

Engineering Knowledge, Curriculum, and a ProActive Philosophy

Engineering curricula are continuously revised and updated in the United States, usually in response to timely studies of pedagogical reform in the Academy. The full impact of these reforms, however, may not be realized without corresponding reforms in teaching, and the instruments and tools necessary to assess teaching and student performance. In the following, the author proposes ideas, many probably well known, which are essential for engineering curriculum and teaching reform. This is followed by a discussion of the ProActive Teaching and Learning Philosophy

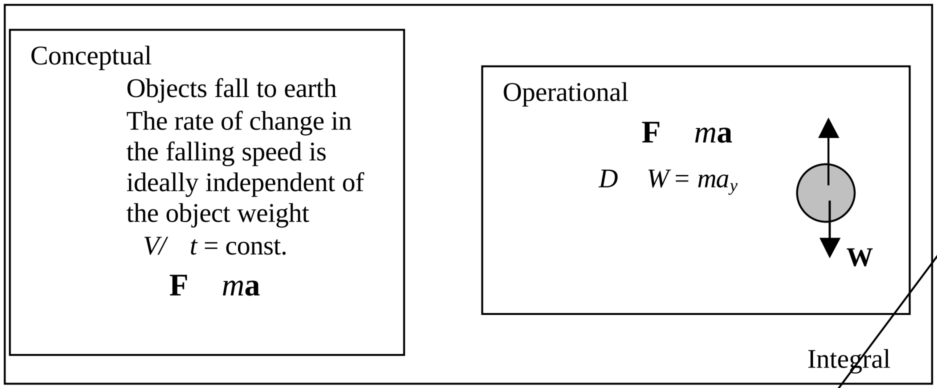
Engineering knowledge consists of three components with the third combining the first two:

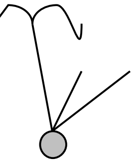
1. *Conceptual knowledge* is based on understanding the “framework”, i.e. the concepts and laws, of the physical world. It is more fundamental than the mathematical representation of the basic or underlying laws because it based upon observations and experience. It is derived from basic scientific facts, often after these facts have been observed repeatedly, until they become part of one’s expectation. For example, everyone quickly learns that when an elevated object is released within a gravitational field, it will fall. Likewise, conceptual knowledge includes the observation that heat flows from a hot object to a cooler one. With conceptual knowledge, and provided with a set of circumstances, one can ‘expect’ or ‘predict’ a qualitative outcome. In general, conceptual knowledge does not require a mathematical formulation. However to be applied in general, it must be presented in a mathematical context.

2. *Operational knowledge* is required for the application of methods, tools, and strategies, i.e., knowledge to solve a problem. This type of knowledge includes calculus, differential equations, statistics, etc. and other learned techniques for elucidating the problem at hand with the goal of finding a solution. Thus operational knowledge includes different strategies for approaching a problem such as visualizing the problem with a sketch, diagram, etc. It also includes examining the problem to seek simplifications and approximations. It could involve a possible reformulation of the problem into a simpler one. In engineering, this will usually include the application of mathematical tools to determine a solution. In the classroom environment, operational knowledge is exemplified in the classical homework and exam problems. With operational knowledge, a student can ‘predict’ a quantitative result; however without conceptual knowledge he or she may have difficulty explaining what the result means.

3. *Integral knowledge* is the synthesis of the conceptual and operational. This synthesis is unique to the engineering profession and is essential for technology development. With this knowledge, engineers that *know* can

Figure 1 is simplistic illustration of the interplay of these types of engineering knowledge with a technology as the product of the application of integral knowledge.





Most engineering curricula correctly emphasize these components; however, the emphasis is usually discrete, creating a series of distinct, unconnected elements. *Disconnects* arise if one component is emphasized at the expense of the others. At the lowest level of a curriculum, disconnects are evident when students are unable to connect conceptual and operational knowledge. For example, given a function $f(x)\quad 4x^2\quad 1$, virtually any sophomore-level engineering student will compute the derivative df/dx with no difficulty. Change the context, however, to: "Given the function $f(x)\quad 4x^2\quad 1$, if x is changed by some infinitesimal amount, what is the approximate corresponding change in $f(x)$?" and even good students may struggle. This is especially true if the question is asked in an engineering course and not a mathematics course. Regardless of the context, students directly associate concepts with the course label. Although the concept of the derivative was probably presented in the context of a rate of change in a mathematics course, probably even in the context of an engineering example, many students will view it purely as a mathematical operation, devoid of any physical or applied interpretation. This is partly because they have not mastered enough engineering science to appreciate the mathematical formulation of engineering concepts. Once the mathematics course is completed, operational knowledge is usually retained, to some degree. Conceptual knowledge evaporates—if it was ever present. Consequently, engineering students may not see a connection between the concepts of preparatory mathematics courses and engineering courses. They cannot appreciate that mathematics is the language for representing and manipulating engineering concepts in an operational form. The situation is exacerbated when sophomore-level engineering science courses focus on problem solution, i.e., operational knowledge, with minimal emphasis upon conceptual or integral knowledge. Students are shown *how* without understanding *why*, consequently they are unable to generalize to *do* beyond the scope of the assigned problems.

To illustrate these observations, consider assignments and examinations for a typical sophomore engineering science course. Good textbooks are designed to present concepts in textual passages coupled with example problems that display operational details in solution strategies and methods. Students often complete reading assignments with little comprehension of concepts, and little attention to examples unless they are similar to assigned homework

Operational

problems. Typical problems again emphasize solution techniques, and with enough examples good students can reproduce the steps to solve specific types of problems, with little understanding of the underlying physical principles. Examinations, typically two or three for the entire course, are patterned after the homework, emphasizing solution techniques. Students usually prepare for an examination, not by carefully reading the text to ensure comprehension but by working as many problems as possible, in the hope that the examination problems will be similar. Based on the criteria of the course, students may excel based solely on their operational knowledge with virtually no conceptual or integrated knowledge.

Conceptual and operational knowledge should *both* be emphasized at every level of the curriculum. Incorporating integral knowledge at every level is not imperative, however. For example, a "traditional" curriculum, generally reserves integral-knowledge emphasis for design and capstone courses. The prerequisite courses are designed to help students achieve proficiency with conceptual and operational knowledge before placing an emphasis upon synthesis and integration. Emphasizing integral knowledge throughout the curriculum, however, helps to eliminate disconnects, enriches the overall educational experience, and encourages students to develop an early "engineering identity." This is the approach embraced in the AE 2000.

ProActive Teaching and Learning

The ProActive Philosophy emerged primarily from the author's learning and teaching experiences, and from observing the interactions of instructors, teachers, and students. True teachers supplement instruction and *enable* students to learn. The teacher's primary objective is to enable students to master the components of knowledge. Thus, a teacher must develop a set of enabling tools and must be able to assess their effectiveness. Enabling students to learn necessarily requires active participation and responsibility for their learning experiences. This is the essence of the ProActive Philosophy:

> *Instruction and learning begin with teacher and student preparation. The classroom is not a place for teachers to show how much they know the classroom is the place to learn what students do not know so those things become known.*

The proactive approach is aggressive and will expose weaknesses in both students and teachers. Students are active participants in the learning process instead of passive recipients. Teachers must have topical mastery and must be spontaneous with an ability to conduct a classroom session without a script. As the rubric implies, proactive learning requires action before students and teachers enter the classroom. Once in the classroom, everyone is engaged. You will not find newspaper reading or other extracurricular activity in the classroom, unless of course, it is assigned.

Obtaining Student Respect, Cooperation, and Participation

We often discuss pedagogy in terms of curriculum reform, teaching and learning styles, etc. without addressing the classroom environment in a social context. Petroski[8] reflects on the deteriorating behavior of students in classrooms. An engaging learning environment must first have mutual respect between the teacher, students, and student assistants. The author has been

The proactive approach ensures that students enter the classroom prepared to learn and it optimizes faculty-student and student-student interaction. As stated, students often do not prepare for in-class learning, even when it is in their best interest. Most students, however, will prepare if there is an *immediate* negative consequence for lack of preparation. Often they are more responsive avoiding negative consequences than they are at seeking positive outcomes. The timing of the negative consequence is much more important than its magnitude. This is the philosophy of the *unit quiz*, a primary instrument used to emphasize and measure conceptual knowledge. The unit quiz is particularly effective in the engineering science courses that may emphasize operational knowledge at the expense of conceptual knowledge.

The Unit Quiz (a.k.a. the Reading Quiz)

Originally referred to as a "unit quiz" because it is based on a "reading unit," in practice it is often referred to as a "reading quiz." This is an inaccurate description, however, since it involves more than reading comprehension. The unit quiz is the defining tool of the ProActive Philosophy. It is somewhat based on the Socratic method with the modification that there is a mixture true/false statements, and short-answer questions, some requiring operational knowledge. It is designed to immediately determine the things that are unknown and the class discussion is directed to make the unknown known. It also provides some measure of the students' abilities to extrapolate conceptual knowledge to answer questions or come to conclusions that are not specifically spelled-out in the text. Panitz[7] and Mazur[6] discuss a similar approach developed by Mazur. Students may initially be confused by the requirement to extrapolate knowledge. They often think that if they read and retain some facts then preparation is complete. This is why a unit quiz should not be referred to these as a reading quiz. Use of this tool requires teacher spontaneity and an ability to enable a learning experience without a script.

The first requirement for effective unit quizzes is a "readable" textbook, or other primary reading source. (Wankat, P. and Oreovicz[12] present a nice discussion on textbook selection.) The tool is not effective unless this criterion is satisfied. The unit quiz has several functions:

> It requires student preparation before class. Students avoid the negative consequence of a low score by reading for comprehension. After one or two quizzes, the importance of reading comprehension is evident.
>
> A properly constructed unit quiz promotes discussion of the fundamental concepts and ideas that would be covered in a conventional lecture. The added benefit, however, is that it provides immediate in-class feedback allowing teachers to respond to knowledge gaps. Engaging the students in arguments to defend their responses, gives an immediate indication of their depth (or lack thereof) of understanding.
>
> Fundamental concepts are reinforced with simple questions requiring illustrative operations that highlight the mathematical expression and application of fundamental physical laws.

The unit quiz requires the teacher to prepare by also reading and comprehending the assigned material to anticipate where the students will have difficulty. The quiz is prepared to highlight the important concepts and ideas presented in the reading, and to probe the depth of comprehension. They must be short, requiring no more than 10 minutes to distribute, complete, and collect for a typical 50-min or 75-min class. As mentioned previously, the questions are usually a series of true/false statements, short-answer questions, and simple mathematical manipulations. Simplicity is paramount, so calculators are not allowed and any calculations requiring a numerical response usua

Aerospace Engineering 2000, A Re-Engineered Curriculum

The Need for Reform

Seely[10] discusses the history of education in American engineering colleges:

> *"Recent efforts to re-emphasize design in engineering schools and develop a better balance with engineering science fit into a history that extends further into the past than two decades … the changes being proposed in the 1990s seek to undo an earlier "re-engineering" of engineering education in the United States, an effort that dominated the first half of this century. Those earlier changes culminated in a substantial reworking of engineering education in the period 1945-1965, and brought into place the style that current reformers wish to overturn, or at least modify. It was only after World War II that American engineering colleges completely embraced engineering science as the foundation of engineering education. That decision led to sharp reductions in the time and coursework devoted to practical skills such as drafting, surveying, and other traditional features of engineering curricula. Replacing them were courses in fundamental sciences, mathematics and engineering science."*

The lesson here is:[10] "A good engineer … must strike a balance between knowing and doing." The recognition of this balance was the impetus for the re-engineered curriculum that is the AE 2000; a curriculum with renewed emphasis on design and hands-on learning to balance the theory of the engineering sciences. Horizontal integration of engineering science topics with hands-on and design experiences is a priority. This is within a learning environment where communications and teamwork development is ubiquitous. Specifically, we have:[9]

Established a core curriculum
Integrated the material in this core
Made the curriculum relevant to applications
Made it experiential, i.e., "hands-on"
Integrated communication and teamwork skills into all courses
Provided more curricular choice at the upper division

cannot be rapidly changed to accommodate the reforms of a single engineering department or school. This arrangement is a common source of the educational disconnects, discussed earlier.

Table 1: Aerospace Engineering Curriculum 2000 for B.S. degree in Aerospace Engineering Sciences, effective fall 2000 semester.

Year	Semester		Credit Hrs	Prerequisite / Co-Requisite (CR)
	Fall			
	APPM 1350	Calculus 1 for Engineers	4	C or better in MATH1100
	ASEN 1000	Intro to Aerospace Engineering*	1	Freshman in Aerospace Engineering
	CHEM 1211	General Chemistry for Engineers	3	One year high school chemistry
	CHEM 1221	General Chemistry for Engineers	2	One year high school chemistry
	GEEN 1400	Engineering Projects	3	Freshman in Engineering
		Humanities/Social Science Elective	3-5	Variable

Our colleagues in the sciences and mathematics recognize this and make attempts to lend engineering relevance to their topics. Ultimately, however, the responsibility is that of the engineering faculty to design curricula that ameliorate these disconnects. This is addressed in the AE 2000.

The AE 2000 provides maximum flexibility in the choice of professional electives. There is no requirement that any of these electives be AES courses. This flexibility reflects the interdisciplinary nature of contemporary aerospace engineering is evident in. While all AES undergraduates are provided a common “core competency,” the multidisciplinary diversity of AES graduates is quite broad.

Sophomore Year: 2000-Series

into integral knowledge. Group reports and/or oral presentations are required with a peer score accounting for 10% of the individual grade.

Table 3 Fall 2001 Schedule for ASEN 2002.

Classwork (3 hr/week)	Experimental Labs (2 hr/week)	Design Labs (2 hr/week)	Exams	Homework (15 hr/week)

Week **Con -0.24 Tw ( ) TjWeek**

Assessment

As expected, proper assessment presents a formidable challenge. AES is pursuing a multi-pronged approach to assessment that includes outcomes assessment for each core course, graduate surveys, student review teams, and other instruments. This is the least developed and implemented part of the new program plan. At the heart of the assessment effort is an outcomes-based assessment tool used to map assignments according to the desired outcome and learning goals. This is essentially a spreadsheet that allows content mapping and weightings to insure learning goals and desired outcomes are achieved. When individual grades are distributed onto this spreadsheet, students and teachers receive direct feedback to determine areas of strengths and weaknesses. In the end, this tool provides information on the overall effectiveness of the course, specifically the general areas of strength and weaknesses. This is then the basis for a continual improvement feedback loop for course content. It also allows teachers to assess their methods in achieving the desired outcomes.

The primary challenge of this assessment tool is the diligence required to make it effective. Teaching assistants, trained to assist in using the assessment tools, have made the process manageable. We continue to work to incorporate the assessment tool along with traditional surveys, etc. and to streamline the assessment process.

Resources and Facilities

Resources and facilities constrain curriculum integration. While faculty may control teaching and learning paradigms at the department level, overall space and resource allocations are generally administered at the college-level. The needs of a unilaterally re-engineered curriculum may not fall into categories used in college budget formulas, and if they do, they may appear exaggerated compared to the needs of conventional curricula. Conventional lecture/recitation engineering science courses are less expensive than a course that integrates these components, in terms of faculty-student contact time, teaching assistants, and experimental and computational facilities. This was evidentei8fd6lda oslan5a1ea 0.996 0 0 aAE mponents, idad 3elyTLL is go3i4a8continuen e

6. Mazur, E., *Peer Instruction, a User's Manual,* Prentice Hall Series in Educational Innovation, Prentice Hall (1997).
7. Panitz, B., "The 15-Minute Lecturer," *ASEE Prism*, Feb. 1998, p. 17.
8. Petroski, H., "Policing the Classroom," *ASEE Prism*, Jan. 2002, p. 15.
9. Seebass, A. R. and Peterson, L. D., "Aerospace Engineering 2000: An Integrated, Hands-On Curriculum," *Frontiers of Computational Fluid Dynamics* 1998, ed. Caughey, D. A. and Hafez, M. M., World Scientific, pp. 449-464 (1998).
10. Seely, B. E., "The Other Re-engineering of Engineering Education, 1900-1965," *Journal of Engineering Education*, **88** (3), Jul. 1999, pp. 285-294.
11. Walker, B. K., Wade, J. E., Orkwis, P. D., Jeng, S.-M., Khosla, P. K., and Slater, G. L., "Development of a Proposed Aerospace Engineering Curriculum for the Twenty-First Century," AIAA Paper 97-0737, 35th Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan. 1997.
12. Wankat, P. and Oreovicz, F., "By the Book," *ASEE Prism*, Apr. 2000, p. 43.

BRIAN ARGROW is Associate Professor and Associate Chair of the Department of Aerospace Engineering Sciences, Univ. Colorado, Boulder. His teaching awards include the W. M. Keck Foundation Excellence in Teaching Award, and the University of Colorado President's Teaching Scholar Award.