Systematic Course Design at The Aerospace Institute

Todd Mosher
The Aerospace Corporation

ABSTRACT

A new course design methodology has been created to aid instructors at The Aerospace Institute, the education and training division of The Aerospace Corporation. This methodology's heritage is an approach described in "The New Professor's Handbook" by Dr. Cliff Davidson and Dr. Susan Ambrose that compares planning a course with planning a research project.[1] For The Aerospace Institute this analogy has been modified to an analogy between course design and systems engineering, which is a concept very familiar to its instructors. This paper walks through this methodology and offers suggestions for implementation that should be useful in a variety of educational environments. Examples are provided throughout to illustrate the concepts.

INTRODUCTION

The Aerospace Institute was established in July 1994 to integrate key corporate educational resources toward The Aerospace Corporation vision to be the world's leader in space technology, planning and system engineering. Since then as a part of their charter, The Aerospace Institute has been developing and offering courses for company personnel as well as the U.S. Air Force, The Aerospace Corporation's principal customer.

One dilemma The Aerospace Institute has faced is how the wealth of technical expertise that is the corporation's major asset can be translated into courses. Also as many of these courses have started into their second and third offerings, The Aerospace Institute has realized through firsthand experience that expertise in a subject, and even exceptional presentation skills, do not necessarily result in the ability to effectively teach a subject.

To address these issues a methodology that embodies an analogy between course design and system engineering has been created. This methodology's heritage is an approach described in "The New Professor's Handbook" by Dr. Cliff Davidson and Dr. Susan Ambrose that compares planning a course with planning a research project.[1] For The Aerospace Institute this analogy has been modified to an analogy between course design and systems engineering, which is a concept very familiar to the various instructors involved in The Aerospace Institute. The remainder of this paper will discuss this methodology.

STEPS IN PLANNING A COURSE

Analogies can be a powerful method to illustrate a concept, especially when they relate something an audience knows to something it doesn't know. The dilemma with The Aerospace

Institute is that the personnel who are asked to be instructors are generally very familiar with systems engineering, the primary charter of The Aerospace Corporation, but are not very familiar with teaching. Thus many instructors resort to the closest analogy they are familiar with, giving presentations of their work, and develop a course that is one giant presentation. The net result is many courses have become an endurance test of how long the students can survive being lectured to and not necessarily a good learning experience.

For example, one week long course with 30 hours of instruction had 737 charts while another three day course with 14 hours of instruction had 450 charts. This shear magnitude of material was actually cut down from previous efforts and reflects a broad diversity of subjects. This makes it difficult for the students to actually learn the material.

Since the presentation approach fails to translate the technical knowledge into good course material another analogy is needed. From this problem arose the author's idea of comparing to systems engineering and course design. Having seen the power of an analogy between course design and planing a research project firsthand through the 1996 National Science Foundation's Future Engineering Educators workshop at Carnegie Mellon University,[2] it was believed a slight modification of this analogy would work well with The Aerospace Institute. The original comparison is shown in Table 1 and the modified version is shown in Table 2.

Table 1
Steps In Planning a Research Project and Planning a Course[1]

Planning a Research Project	Planning a Course
1 Determine possible funding agencies and their interests.	1 Determine the backgrounds and interests of the possible students.
2 Choose the objectives of the research based on these interests as well as your expertise.	2 Choose the objectives of the course based on the student information and on the skills and knowledge which you deem appropriate to teach given your expertise.
3 Choose the scope and content of the research based on time and money constraints.	3 Choose the scope and content of the course based on time and money constraints.
4 Develop a research plan to achieve the objectives within the scope. The plan may include several different research approaches.	4 Develop the learning experiences to achieve the objectives within the scope. These experiences may include several different learning activities.
5 Develop procedures to evaluate the success of the project and methods to disseminate the results.	5 Plan feedback and evaluation of student learning through tests, written reports, and other assessment techniques.
6 Prepare a final proposal based on the above considerations.	6 Prepare a syllabus based on the above considerations.

In Table 2, steps for a system engineering study roughly correspond to the steps in a typical systems engineering process; input requirements, function analysis, synthesis, evaluation and decision, and document solutions.[3] This process is illustrated in Figure 1. The real power of this comparison is many of the methods used to perform systems engineering can also be applied to course design. These will be cited as the process is described. Each of the steps in planning a course will now be described using the analogy to systems engineering where it strengthens the explanation.

Table 2
Steps In A Typical Systems Engineering Process and Planning a Course

Systems Engineering Study	Planning a Course
1 Determine customer requirements and objectives.	1 Determine the backgrounds and interests of the possible students.
2 Determine the functions to be performed to meet requirements as well as possible elements to perform these functions.	2 Choose the objectives of the course based on the student information and on the skills and knowledge which you deem appropriate to teach given your expertise.
3 Choose the concepts to study further based on time and money constraints.	3 Choose the scope and content of the course based on time and money constraints.
4 Develop the chosen concepts further to achieve the objectives and requirements. The concepts may include several different approaches.	4 Develop the learning experiences to achieve the objectives within the scope. These experiences may include several different learning activities.
5 Develop measures to evaluate the different concepts and methods to document these differences.	5 Plan feedback and evaluation of student learning through tests, written reports, and other assessment techniques.
6 Document study results capturing above considerations.	6 Prepare a syllabus based on the above considerations.

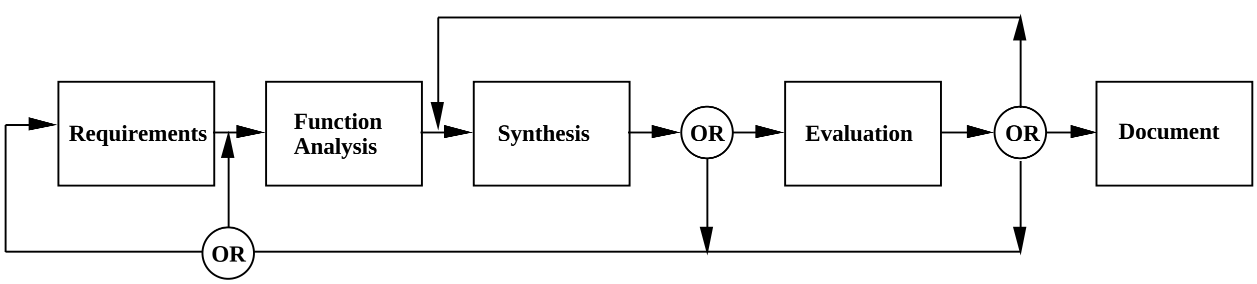

Figure 1 Typical Systems Engineering Process

ASSESS THE BACKGROUNDS AND INTERESTS OF THE STUDENTS

Essential to designing an effective course is knowledge of the potential students skills, interests and backgrounds. The learning activities must be designed to the appropriate level so as not to either overwhelm students by being too difficult too quickly or bore them by being too simple. Knowing the customer is essential to designing a good course or a good system.

The simplest way to assess student backgrounds is a pre-course survey. Such a survey has been used effectively in the Concept Development course at The Aerospace Institute to help instructors gauge their material as well as to establish the proper skills mix for forming design groups. The survey consisted of questions about the student's experience, area of expertise, and experience with Microsoft Excel and PCs.[4] The initial questions are important for The Aerospace Institute because the students have a wide variety of backgrounds. The computer questions are relevant so that expertise can be spread among the groups and to get a feel for how simplified the computer work must be designed. For a university setting you might ask questions about the students previous course work and computer experience if relevant to the learning experiences to be employed. Another common practice is to issue a pre-test to gauge student's abilities.[1]

What is perhaps more difficult to gauge is the students different strengths and preferences in the methods by which they ingest and process information. Some students work better interactively, while others need time to reflect. Some students prefer focusing on hard data, while others like things in a more abstract form. Some respond to visual presentation, such as diagrams and schematics, while others prefer written and spoken explanations. Collectively these differences are captured by the concept of learning styles.[5]

There are four learning style models that have been used effectively in engineering education to help both students and instructors determine learning preferences: The Myers-Briggs Type Indicator, Kolb's Learning Style Model, Herrmann Brain Dominance Instrument, and the Felder-Silverman Learning Style Model.[5] Without digressing into a discussion of each of these models, they all have their strengths and weaknesses in characterizing a student population. If an instructor has time to utilize these instruments and adjust based upon their results, they can be worth the effort.

However, time is always of concern with the design of courses at The Aerospace Institute and can be in many other settings as well. Sacrificing some of the course content to perform this study may not be practical in the time lost and the fact that there is probably no time to adjust the course based upon the results. But, one important lesson of knowing that a variety of learning styles will exist in a course's student population is the concept of "teaching around the cycle."

Traditional engineering instruction (and a large percentage of the instruction at The Aerospace Institute) focuses exclusively on lecturing, a style that is only comfortable to a certain type of learner. To reach all types of learners, an instructor should explain the relevance of each new topic, present the basic information and methods associated with the topic, provide opportunities for putting the methods into practice, and encourage the exploration of other applications.[5] It is also important to provide timely and constructive feedback. Therefore introducing this variety of instructional methods can have a large effect on the design of the course and at the same time appeal to many of the learning styles likely to be present in the student population.

All of this information gathering underscores an important point: an instructor must take the characteristics of the students into account as the primary factor in deciding the methods and the subjects to teach.[1] Since this information gathering can be difficult and one may be unsure of what to do with it after it is gathered, capturing students' backgrounds and interests takes experimentation just like determining requirements in systems engineering. Few instructors or designers are able to ever get it right on the very first try.

CHOOSE THE COURSE OBJECTIVES

Objectives serve different purposes for the instructor and the students. For the instructor, the objectives can be used as the skeleton around which the class will be built. For the students they can serve as cues to indicate what they should be learning. The objectives should indicate the expected knowledge and the competence of the students by the end of the course. In fact, learning objectives can be set up for every single lecture. An example of learning objectives for a Aerospace Institute lecture on launch vehicles is shown in Figure 2.

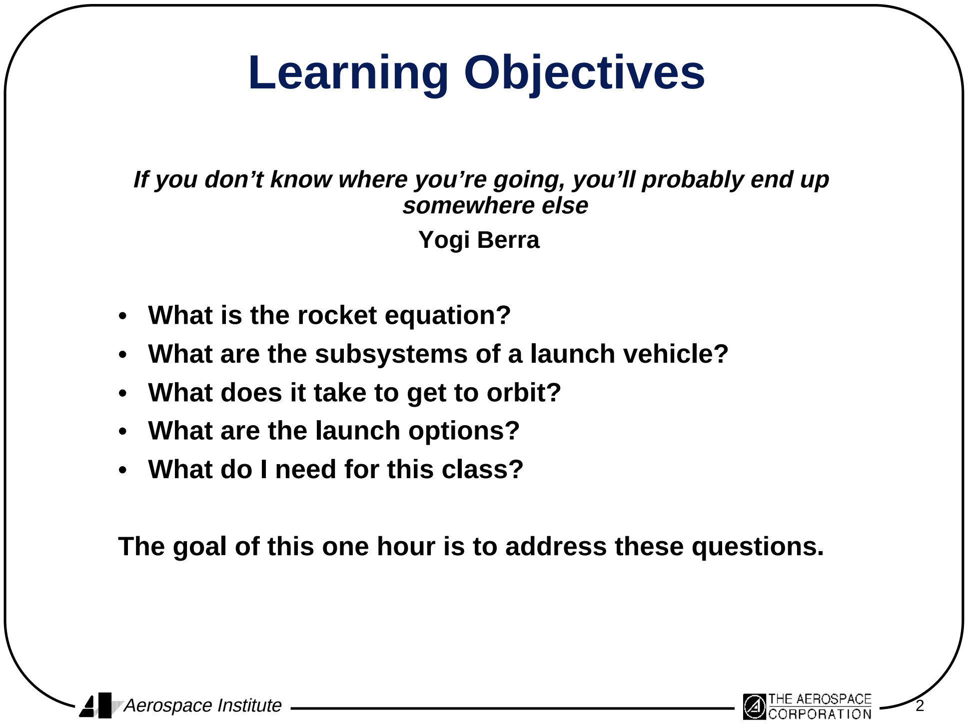

Figure 2 Launch Vehicle Lecture Learning Objectives[6]

Objectives may vary greatly depending on whether the course is to provide depth in a specific subject or breadth over a wide range of subjects. As in using different learning methods to meet different learning styles, variety is the key to setting objectives so as to appeal to the student diversity in any one class.

One guideline for setting course objectives is to use the Bloom Taxonomy.[7] Summarized below it represents some basic goals of education. In choosing course objectives it is important to consider how your course will meet all or some of these goals with the chosen material.

1. <u>Knowledge</u>- the ability to recall specific pieces of information such as remembering dates, facts definitions or concepts.
2. <u>Comprehension</u>- the ability to render the material into another form such as translation, interpretation, or extrapolation.
3. <u>Application</u>- the ability to appropriately abstract material to unfamiliar problems.
4. <u>Analysis</u>- the ability to break a problem into its components and explain the hierarchical relationships.
5. <u>Synthesis</u>- the ability to create something original after having broken the material into its components.
6. <u>Evaluation</u>- the ability to judge a product based on a set of predetermined criteria.

DETERMINE THE SCOPE AND CONTENT OF THE COURSE

A real limit in the development of a course is time, and in some cases money as well. There is never enough time to cover the "essential" topics in a course. This is compounded by the fact that coverage is not teaching, an important difference between presentations and teaching. It is not enough to simply present all of the material if the goal is to really teach it. As was often stated at the NSF Workshop, "coverage is the enemy of teaching."[2]

How is the problem of too much material, a need to help students learn it (i.e. achieve some or all of the Bloom Taxonomy goals), and too little time to be solved? This dilemma ties in nicely with the analogy to systems engineering and specifically functional analysis. Functional analysis is a two step process of identifying the functions to be performed (in this case identifying the course objectives) and functional allocation (or allocating learning activities to course objectives).

A simple way to apply functional analysis to course design is the creation of two matrices. The first matrix has the subject areas along the top and the course objectives along the one side. Identifying the relationship between the subjects and the learning objectives is done with an X or some shading at their intersection. The second matrix matches the selected subjects with the learning experiences (lectures, computer lab work, etc.). These are represented in Figure 3.

Subjects

Objectives

Subject / Objectives	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles
CD Role in SSE	●																●
Concept from Need		●	●	●	●	●										●	
Sys Perf/Mission Effec		●			●	●	●									●	
Sys Design/Sys Perf								●	●	●	●	●	●	●	●		
CD Tools & Methods		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
ID Resources/Expertise	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	

Subjects

Learning Experiences

Subject / Learning Experiences	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles	Launch Vehicles
CD Role in SSE	●																●
Concept from Need		●	●	●	●	●										●	
Sys Perf/Mission Effec		●			●	●	●									●	
Sys Design/Sys Perf								●	●	●	●	●	●	●	●		
CD Tools & Methods		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
ID Resources/Expertise	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	

Figure 3 Functional Analysis Matrices

The first matrix can serve two purposes. First, it makes sure that when each of the topics is covered, the learning objectives it is serving are indeed met. Second, in the case where there is too much material, it is easier to choose which subjects to leave out based on how many learning objectives they are serving.

The second matrix helps to allocate the limited resource of time (and sometimes money if different learning experiences have a cost associated with them such as specific computer software). By matching learning experiences and their durations with the subjects to be taught, it will become evident if each of the subjects selected via the first matrix can be covered. If not, then a further reduction of the topics will be required based on the time constraint (but also again considering which topics meet the fewest learning objectives).

Using this approach is much more constructive in creating an integrated course than other methods in which material is paired down simply by covering two less chapters in the text or arbitrarily eliminating lectures. It also generally results in a flow of topics that is easier to explain to the students, since explaining to them will help them to understand the flow of the course better and how it relates to other classes.

Another way to determine course content and to accommodate the wide range of backgrounds, interests and abilities among the students is to consider three categories of material to be covered:

- basic material which should be mastered by every student in the course,
- recommended material which should only be mastered by those students seeking a thorough knowledge of the subject, and
- optional material which is intended for only those students with special interests beyond the scope of the course.[1]

It is essential that the basic material is provided for in the class, while the optional, and even parts of the recommended material, can be provided as appendices, independent exercises outside class or optional reading material.

DEVELOP THE COURSE LEARNING EXPERIENCES

This activity is really an extension of the second matrix subjects vs. learning experiences discussed in the previous section. Once the material to be covered has been downselected it is important to flush out the learning experiences. In a university setting these commonly include lectures, recitation sessions, in-class problem solving exercises, tests, oral presentations, group projects, laboratory sessions, homework assignments and other activities.

Developing the learning experiences starts with choosing the textbook or other reading material. For some subjects there is an established text that matches up with many course designs directly. In some other cases an established text augmented with other material may best meet your learning objectives. Finally, due to the specialization of the material, the instructor may have to completely develop the text from scratch (an often time consuming undertaking that can be worthwhile if one is left trying to heavily augment an inadequate text). No matter what the choice, the intention should never be to simply repeat the information from the text or reading material in class. This is not an effective use of time and will do little to keep the students engaged in the class which is an important part of learning. The text should serve as meat on the skeleton structure developed earlier for the class, not as the skeleton itself. Even with good textbook material available, one should not necessarily adopt their chapter structure as the necessary sequence. The objectives of this specific class are likely to be different than the original objectives of the text. The important point in choosing to move around is that the purpose for not following the chapter order be clearly described to the students so as to prevent confusion.

Next, revisit the second matrix of subjects vs. learning experiences created previously and flesh these activities out. Look for a variety of activities and then map them to the calendar of the course. Developing this schedule will help keep the instructor honest as well as communicate expectations to the students.

Finally, review all of the material for integration. An important part of systems engineering as well as course design is to create an integrated product. Integration insures that all of the learning objectives, subjects and learning experiences are coordinated and mesh well together.

PLAN COURSE FEEDBACK AND EVALUATION

It is important that both students and instructors measure their performance and effectiveness. Referred to as Measures of Effectiveness (MOEs) or Measures of Performance (MOPs) in the systems engineering world, they should be applied to both the students working in the course and the course itself.

For students, common mechanisms include quizzes, exams, student presentations, written reports and graded problem sets. In-class exercises such as discussions and real-time problem solving can also be used to gauge the learning taking place. For group projects it is often helpful to have the students evaluate each other as this can provide insight beyond that seen normally by the instructor. A balance of these mechanisms results in some sort of grade. It is important to let students know at the start of each class how this evaluation will be determined.

If the course is to improve, then it is important that the instructor also gets feedback. Does the selection of topics and learning experiences meet the learning objectives stated? Could certain topics be better taught using some other method than the learning experience used? Student feedback if constructively gathered can provide a lot of insight into course design. Like the systems engineering process, the course can get this far and still need to go back to the beginning to start again at any of the earlier steps.

PREPARE A SYLLABUS

With all of the preparatory work done it is important to document the work performed, especially because often it is necessary to revisit many steps in this process as the course evolves and is taught several times. The mechanism for course design is the syllabus and it is likely the first document presented to the students. Thus since first impressions can be important, it is necessary that the syllabus be well prepared. Fortunately if this process is used, generating a syllabus is simply a documentation of the earlier steps in the course design process.

The syllabus should explain the rationale, purpose, content and procedures of the course. Some other important information to consider including is:

- Basic information about the course including name of the institution, credit value (if any), time frame of the class, class location and prerequisites.
- Relevant instructor information including names, phone numbers, email addresses etc.
- Brief course description that attempts to summarize the subject material, motivate students to participate, and explain how parts of the course work together.
- The list of the course objectives developed in the earlier steps of the process.
- Information about learning experiences in the class. If appropriate the two matrices of learning objectives vs. subjects and learning experiences vs. subjects could be included.

- Procedures and policies of the course such as method of evaluation, attendance requirements, deadlines and the treatment of late work.
- A course calendar showing how learning experiences are mapped to the class time frame.

SUMMARY

This paper presented a method to design courses using an analogy to systems engineering as an illustration. It showed how one begins with understanding the students background and interests, chooses the objectives of the class, defines the scope and content of the class with time generally being the limiting factor, and develops learning experiences around the structure of the learning objectives. With this in place, course feedback and evaluation is planned and a syllabus created to document the results of this process. Throughout this paper examples and suggestions are provided to help instructors in utilizing this approach.

Like all good systems engineering projects, and all good course design, this prescribed process to design courses will continue to iterate and evolve. One forum which is expected to provide numerous possible improvements will be the ASEE annual conference where this is being presented. Another place for expected feedback is the continual offering of this approach as a seminar for instructors of the Aerospace Institute. Perhaps with sufficient refinement, a second release of this paper will be merited.

References

1. Ambrose, S.A. and Davidson, C.I., The New Professor's Handbook, Bolton, MA: Anker Publishing Company, 1994.
2. Ambrose, S.A. and Davidson, C.I., Preparing Engineering Faculty of the Future, The National Science Foundation Engineering Scholars Workshop, Pittsburgh, PA: Carnegie Mellon University, July 21-26, 1996.
3. Defense Systems Management College, Systems Engineering Management Guide, Springfield, VA: U.S. Department of Commerce, January, 1990.
4. Schulenburg, N., Personal Communication, March 14, 1997.
5. Felder, R., Matters of Style, ASEE Prism, pp. 18-21, December 1996.
6. Mosher, T., Launch Vehicles, Space Systems Engineering-Concept Development, El Segundo, CA: The Aerospace Corporation, 1997.
7. Bloom, B.S., Hastings, J.T. and Madaus, G.F., Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1, Cognitive Domain, New York, NY: McCay, 1956.

About the Author

Todd Mosher is a Member of the Technical Staff of The Aerospace Corporation and an Instructor for The Aerospace Institute. He is in the process of completing (anticipated graduation Summer, 1997) his Ph.D. in Aerospace Engineering from the University of Colorado. He also holds a B.Sc. in Aerospace Engineering from San Diego State University (1989), a M.S. in Systems Engineering from the University of Alabama in Huntsville (1992) and a M.S. in Aerospace Engineering (1995).