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The Department of Systems Engineering at the United States Military Academy (USMA) at West Point teaches two distinct audiences of students in its curriculum. The first is those cadets who pursue one of the majors offered by the department: Systems Engineering, Systems Management, Information Engineering, or Engineering Management. The second audience is those cadets who are not pursuing a math, science or engineering major. Those cadets take a three-course engineering sequence in the department, the goal of which is to "enhance[e] their quantitative problem-solving skills and … provid[e] introductory engineering design experiences."[1] The sequence culminates with a capstone course in which the cadets work with a real client to solve a problem for him or her. That course is SE450, Project Management and System Design. This paper focuses strictly on that course, which has been successful in achieving both department and Academy goals by aligning the course assignments to a decision making process and incorporating a real-world client into the course.

This paper will begin by comparing the findings of some of the relevant literature regarding capstone courses to observations in our course, after which we will describe the academic environment at the Military Academy and where systems engineering fits. We will then discuss the Systems Engineering and Management Process (SEMP), its four phases and how we align our assignments to it. We will also briefly discuss the selection of the clients and the interaction they have with cadets. Finally, we will discuss how the ideas used in this course can be applied to different processes to teach a decision-making method or process.

Literature Review

There is a great deal of literature in the field regarding capstone courses, but relatively little regarding the introduction of engineering topics to non-engineering students, especially doing so in one semester. Diane Rover and P. David Fisher describe their course goals and underlying purpose behind the capstone course they developed for computer engineering at Michigan State University. Those goals and purpose are very similar to that of SE450, although they discuss in some detail the "cross-functional" teams that they create in their capstone groups.[2] That "cross-functionality" occurs less formally in this course, because they all have different majors and therefore different strengths. James Steele writes about James Madison University's implementation of the capstone course in sociology.[3] Although there are great differences in the fields, there is similarity to that used in SE450. He also describes a common challenge: the difficulty in assessing a teams' performance. The client interaction mitigates that challenge in SE450, because that external but very interested observer gives a completely different perspective to consider in evaluation. Steele further describes another common challenge – that of motivating and instructing his students to synthesize previous work.

As for the design of the course, the Electrical and Computer Engineering Department at the University of Alabama constructed their capstone course around several smaller requirements. Doing so throughout the course created an effective learning environment for their students.[4] SE450 has a similar approach, in that there are many small assignments in the semester, which together create a study of an entire project. Finally, the US Air Force Academy has a very similar course in their Department of Civil and Environmental Engineering. In comparing the two, they have similar goals and also incorporate a real-world scenario. They have had success in using the client, which bears out as well in SE450. However, their focus is primarily on the project management perspective, rather than the engineering design or decision making approach.[5]

Academic Environment at the Military Academy

The United States Military Academy has the mission to "educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army."[6] To achieve this mission, the Academy instructs cadets in the military, physical, and academic domains, and each is essential for a cadet's development. Academically, cadets choose a major from one of thirteen academic departments. Regardless of their major, all graduates earn a Bachelor of Science degree, a result of the high concentration of math and science courses required as part of the core curriculum.

The Dean of the Academic Board recently wrote Educating Future Army Officers for a Changing World, which states the Dean's developmental goals for cadets. That document sets the standard that "graduates apply mathematics, science, technology, and the engineering design process to devise technological problem solutions that are effective and adaptable."[7] Toward that goal, it sets out the policy that all cadets who do not pursue an engineering major take a three-course engineering sequence in civil, electrical, environmental, mechanical, nuclear or systems engineering. The purpose of the sequence is to introduce cadets to the engineering design process. The sequence is to include a "well-integrated progression from predominantly engineering science to predominantly engineering design, and a culminating design project."[8]

For Systems Engineering, the first course in the engineering sequence is SE300, Introduction to Systems Engineering, and teaches cadets the Systems Engineering and Management Process, or SEMP, a problem-solving methodology used by cadets and faculty in the department. The second course, SE350, Systems Modeling and Design, introduces the cadets to analytical modeling tools such as forecasting, economic analysis and simulation that could be used to try to solve a systems engineering problem. The capstone course is SE450, Project Management and System Design, which is focused on the "culminating design project" called for by the Dean. In order to grasp the strategy and structure of this third course, it is necessary to first understand the nature of the academic environment, then describe the SEMP and the associated class assignments.

Classes at the Military Academy are small by design, limited to 18 or fewer cadets in each class hour. Each semester has 40 lessons or class meetings, and each class period is 55 minutes long. All the cadets in SE450 are seniors, and as mentioned above, none are engineering majors. In any given semester, there are approximately 110 cadets in the entire course, spread over 6-7 class hours or sections. Each section has its own project, and all cadets work on that project in groups of 3-5. Having one project in each class simplifies class preparation for the instructor and is not a burden to the client. This also provides the client with several feasible alternatives to consider. The course has 1000 points possible, earned over the course of the semester through interim assignments, presentation and papers.

There are 1000 points possible in the course, 380 of which are earned individually. This allows a particularly strong cadet to excel and not be unfavorably assessed based on the poor performance of his or her group members. Those points are assessed based on a peer review system for each major assignment and four quizzes (see table below). The quiz material is a review from their previous courses in the sequence, SE300 and SE350, and should serve as a preview of the material to come as their project moves forward in the SEMP.

Event	**Lesson**	**Total Points**	**Individual**	**Group**	**% Course**
Design Project Workshops (DPW) (7)	Various	80	10	70	8.0%
Quizzes	Various	210	210	-	21.0%
Interim Progress Review (IPR1)	13	130	30	100	13.0%
Interim Technical Report (ITR)	16	130	30	100	13.0%
Decision Brief (DB)	32	160	40	120	16.0%
Implementation IPR (IPR2)	36	110	20	90	11.0%
Final Technical Report (FTR)	39	180	40	140	18.0%
Totals		**1000**	**380**	**620**	100.0%

Table 1: Assignments and point allocation for SE450 (AT 2006-2)[9]

Systems Engineering and Management Process

The Department of Systems Engineering teaches and uses the Systems Engineering and Management Process as a problem-solving technique. The SEMP has four phases, each of which has two or three steps and involves a number of analytical tools to assist an analyst in moving forward in a project. The SEMP is iterative, so an analyst can move back and forth between phases when required. In SE450, the cadet teams take on the role of analyst and perform the tasks required in these phases.

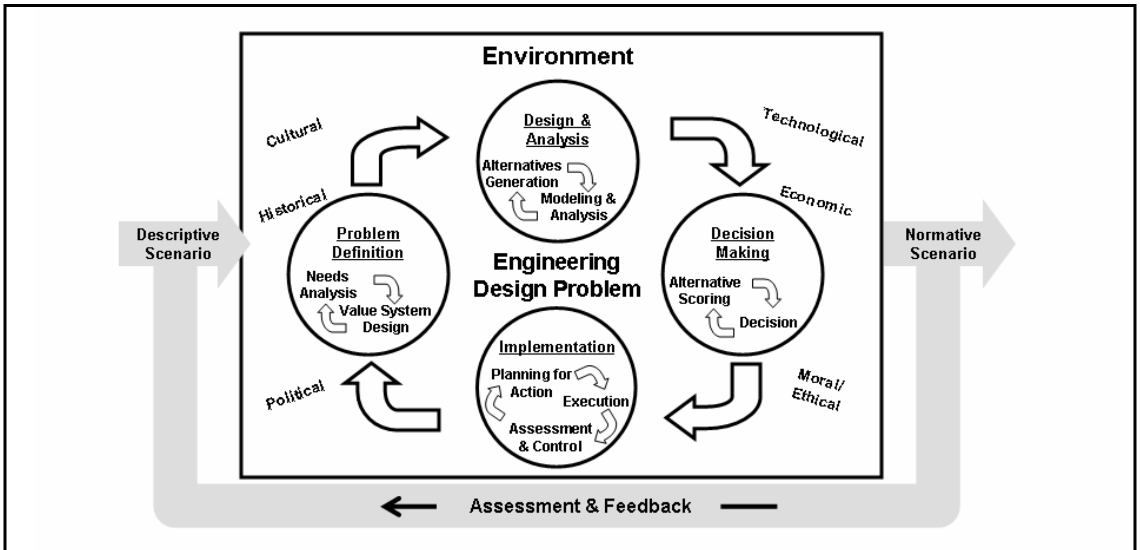

Figure 1: Systems Engineering and Management Process (SEMP)[10]

The first phase of the SEMP, Problem Definition, includes the steps of Needs Analysis and Value System Design. It is very research-intensive and forms the foundation of the entire project. This phase begins when the instructor arranges for the client to attend a class in the first 2 weeks of the semester, provide a short synopsis of the problem, and then answer questions. Based on that interview, the cadets develop an initial problem statement and proceed into a detailed study of the needs of the system. They focus on identifying the system's larger environment, the components of the system itself and how those components work together to accomplish the desired functions. The cadets also are required to conduct internet research, seek out other stakeholders, conduct surveys, or do other types of investigation to discover the information required. They organize this data into a number of forms, such as system decomposition diagrams, context diagrams, functional hierarchies and flow diagrams.[11] This information guides the analyst to an appreciation of the relative importance of the functions of the system and leads to the design of the value system. Based on that knowledge, the cadets identify and organize specific, measurable objectives and evaluation measures in a value hierarchy. Once agreed to by the client, the value hierarchy becomes a critical product that moves to the next phase of the SEMP:

All of this work is captured in three 10 point exercises (each is worth 1% of the total course) or Design Project Workshops (DPW). The DPWs are either papers collected by the instructor or presentations delivered by the group to the instructor. While this is a small number of points, it is emphasized throughout the semester that the DPWs are meant to be interim requirements, not necessarily fully-formed results and analysis. They ensure the cadets are making progress and indicate when a group is in need of redirection. The instructors expect the work to be in-depth and complete at the in-progress review (IPR) and the interim technical report (ITR), both of which occur within 2 weeks of the DPW submission. The IPR is a presentation to the client himself, and is tailored to that audience. The ITR is a fairly-well preformatted paper describing their results, due on lesson 16 (almost halfway through the course). It is used more by the instructor to assess their technical progress. Each of these products is worth 130 points (13% of course grade). Having presented their early work to the client for review gets the project started and gains the necessary concurrence from the decision maker to move into the Design and Analysis phase of the SEMP.

The cadets then start the Design and Analysis phase of the SEMP, the focus of which is generating and modeling many alternatives. They spend the next 7 lessons (about 3 weeks) in the Design and Analysis phase. The instructors try to guide them through generating their alternatives, trying to keep them from focusing on "how" the functions currently get done and prefer that they consider a wide range of options that could perform the needed functions. The idea at this early point is to be as inclusive as possible, so the groups should use a number of different methods to generate the alternatives, from merely modifying the existing system to a wholesale change envisioned by using a morphological box approach. The cadets develop at least 15 alternatives and submit them in another 10-point DPW.

They then move into modeling the alternatives, which is always difficult given the background of the students. A course goal is for them to use some sort of analytical method to model these various alternatives, but the important point is to communicate the idea that they need to predict the performance of each alternative with respect to the evaluation measures identified in Problem Definition. Their methods are generally sound, although not always as quantitative as desired or possible. The end result is a raw data matrix, which again is presented to the decision maker for review and a "common sense" check. The rigor involved in the modeling process is completely dependent on the project itself, and many times, the client is able to validate their results or guide them another way. Once the raw data matrix is complete, it falls to the cadets to make a recommendation, which is done in the Decision Making phase of the SEMP.

Cadet-client interaction is absolutely critical at this point. The cadets must take the initiative to sit down and discuss their raw data matrix and learn the client's feelings about each alternative's performance. The instructor's role is largely to emphasize the importance of that client interaction, as well as to remind the cadets of the detail needed in this scoring process. This scoring allows the analyst to evaluate the performance of each alternative with respect to the functions. Ultimately those value scores combine in a weighted average to become an alternative's total value score. The cadets submit the result of that alternative scoring, as well as an analysis of the sensitivity of their recommendation, in another 10 point DPW. This is followed quickly by another 10 point DPW in which the cadets analyze their alternatives in terms of cost. The goal is to force the cadets to see and evaluate all of the alternatives based on cost and performance. Having completed those required tasks, the cadets present their recommendation for their client's approval on lesson 32. This represents 160 points and at 16% of the course grade, is the second-largest single requirement in the course. Although this concludes the Decision Making phase, the teams still must plan how to implement their alternative.

As the project moves into the Implementation phase, the cadets develop a plan to enact the recommended alternative. This means more than just identifying the tasks that must be accomplished and resources to be used; it requires an understanding of which tasks will be most difficult or costly, as well as recognizing any organizational barriers that must be overcome. It also includes a detailed timeline of which steps should be taken in which order. Finally, the cadets specify a set of measures to assess the performance of the system after implementation. Ultimately, they should come away with a basic understanding of some of the difficulties in implementing any plan. This culminates on lesson 36 with an Implementation IPR, which is much more of a discussion with the client about the items they identify. This IPR is worth 110 points. The cadets finish the semester with a final technical report (FTR) due on lesson 40, which includes all of their work, as well as the comments from the implementation IPR. It is the largest requirement in the course, at 180 points and carrying 18% of the course grade.

Throughout the course we return to the concept of project management. We require the cadets to create a semester-long project plan in Microsoft Project, and to continually update that plan as they accomplish tasks. Additionally, each group has a lead engineer position, who is responsible for updating the schedule, ensuring required tasks are addressed and completed, and generally organizing the group. The lead engineer earns a grade as part of his or her individual grades associated with the major assignments. The lead engineer is also called upon at times to present the group's progress, especially during periods of the course when the group is working independently.

As described above, the client or decision maker interaction is critical to the success of the project and of the class. In each phase, the client must be available to answer questions, review work and provide guidance or redirection as needed. Obviously, this is strongly dependent on the nature of the project itself. In past semesters the cadets have investigated topics as technically rigorous as determining the best use of unmanned aerial vehicles or high-energy lasers, as well as those with much less technical rigor, such as developing a policy to increase awareness of diversity in the classroom or improving a parking system at the local high school. In all cases, the client should be located nearby, so that the cadets can have easy access to ask questions or meet. Each instructor also meets with the client ahead of time to give them an idea of what to expect and what is expected of them throughout the semester. The client's personality also plays an important role in the class, since it forces the cadets to deal with a person normally outside of their experiences. All of those facets of the interaction are important parts of the course and its method of achieving its goals.

This method of aligning the coursework to an already-existing process could be used in a range of applications. Anywhere a number of fairly discrete steps are used to analyze a situation or develop a solution, it may be possible to tie those steps to the class assignments. As in SE450, the instructor becomes a guide, reminding students of the underlying process and where it is headed. Doing so allows the students to focus their attention to a specific, short-term requirement, then back away from that individual event, consider the entire process and where they are, and move forward with the project. This is only heightened when a real-world client is involved. Any student who is too focused on the short-term is quickly reminded by that individual that there is a greater goal to achieve, and that the discrete, short-term requirement is just that.

The reliance on the real-world client is the source of the largest weakness in the course design. A client who is willing to be involved in the process, available for answering questions and providing feedback and who enjoys the discussions with the cadets is an excellent resource for the instructor. The cadets truly get to learn about a system and try to apply a problem-solving method to it. There is also great value in forcing them to interact with someone of a different background – not their instructor or someone in a chain of command position. However, clients who are not able to provide the time or energy to the process lead to cadet groups that are not interested in the project and do not engage with the material. It is important in the first meeting between the instructor and the client (before the semester starts) to discuss the expectations of both parties.

In general, SE450 has been successful at introducing the engineering decision process to our audience of non-engineering cadets. In course-end feedback, 147 of 224 cadets either agreed or strongly agreed that "this course improved my ability to solve real-world problems through quantitative techniques." 144 of the 224 agreed or strongly agreed that "this course taught me to apply the engineering design process and use appropriate technology to develop solutions that are both effective and adaptable." Informally, cadets accept that the SEMP is a technique that could be used to solve a wide range of problems, but they were skeptical at its use in some of the simpler projects. Nonetheless, by using the entire process, they were able to build a strong foundation to support a solid recommendation.

In this paper, we have tried to describe our efforts at creating a worthwhile capstone experience for senior cadets at the US Military Academy. Our goal throughout the course is to introduce an audience of non-engineering cadets to an engineering design process. We do this by aligning the course structure and assignments to that process, while incorporating a client into the class to add realism and provide information. Organizing the class in this fashion, we feel we have met our goal of exposing the cadets to the process, as well as the Academy's goal of creating graduates who are able to respond effectively to an unclear problem.

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[1] Kaufman, Daniel J., Educating Future Army Officers for a Changing World, undated, page 28. Available online at http://www.dean.usma.edu/support/aad/EFAOCW.pdf, accessed January 17, 2006.

[2] Rover, Diane T., Fisher, P. David, "Cross-Functional Teaming in a Capstone Engineering Design Course," accepted for presentation in the *Proceedings of the 1997 Frontiers in Education Conference*, accessed on December 14, 2005 at http://www.egr.msu.edu/classes/ee482s97/reading/fie97_rf.pdf.

[3] Steele, James L., "The Laden Cart: The Senior Capstone Course," *Teaching Sociology*, vol. 21, No. 3, (July 1993), pp. 242-246, accessed online at http://links.jstor.org/sici?sici=0092-055X%28199307%2921%3A3%3C242%3ATLCTSC%3E2.0.CO%3B2-K on January 17, 2006.

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[5] Jenkins, S. Rod, et al., "Capstone Course in an Integrated Engineering Curriculum," *Journal of Professional Issues in Engineering Education and Practice*, (April 2002), pp. 75-82.

[6] US Military Academy Website, www.usma.edu/mission.asp, accessed January 17, 2006.

[7] Kaufman, pg. 26.

[8] Ibid, 28.

[9] Project Management and System Design, Instructional Memorandum, Academic Term 2006-2 (spring semester), signed 5 January 2006.

[10] Readings for Systems Engineering & Engineering Management, Various authors, Wadsworth Group, Thomson Learning, Inc., Belmont, California, 2003.

[11] For a detailed description of these tools, see Athey, Thomas H., Systematic Systems Approach, An Integrated Method for Solving Problems, Prentice-Hall, Inc., Upper Saddle River, New Jersey 1982, or Readings for Systems Engineering & Engineering Management, Various authors, Wadsworth Group, Thomson Learning, Inc., Belmont, California, 2003, or Supplemental Readings for Systems Engineering and Engineering Management, Various authors, John Wiley & Sons, Hoboken, NJ, 2005. We use each of these books in SE300 and again in SE450.