ACADEMIC FORUM

Panel: Integrating Systems Engineering into Engineering Curricula through Capstone Projects

Beth McGrath, beth.mcgrath@incose.org

Moderator: Beth McGrath, *Stevens Institute of Technology*
Panelists: James Nemes, *Pennsylvania State University*; **David Umphress,** *Auburn University*; **David Olwell, US** *Naval Postgraduate School*

A nineteen-month research study sponsored by the US Department of Defense is underway, with the goal of understanding the impact on student learning of systems engineering as well as career interest in the discipline. The project is pursuing this goal through a set of diverse pilot systems and engineering capstone experiences, which the defense department is funding in eight civilian universities and six military academies in the United States. Students worked in teams in the context of a capstone course over one to three semesters to produce an actual product or artifact. Each university selected at least one of four authentic problem areas from the Department of Defense (DoD) for students to focus on. Systems engineering faculty led the conceptualization, development, and implementation of the program in most projects, but other faculty, particularly from mechanical engineering and computer science, were involved as well.

Almost half of the nearly 300 students participating were undergraduates. Four institutions held courses for graduate students only, and three had mixed undergraduate and graduate populations. Fully 41 percent of all students who participated in the programs reported a high level of interest in becoming a systems engineer. Approximately the same percentage reported a high interest in working in this capacity for the government.

Preliminary findings from the pilot projects included challenges related to teaching the broad topic of systems engineering to students majoring in fields other than systems engineering; ensuring equivalent grading policies in multidisciplinary student teams; finding meaningful ways for students majoring in other disciplines to contribute to problem areas specific to particular domains; and motivating external mentors to bring authentic professional experiences to the learning experience and helping these mentors to stay involved.

Pennsylvania State University's approach to this program was to introduce systems engineering principles to undergraduates from the traditional engineering disciplines and allow the students to apply them in a meaningful way through their capstone design class. An existing multidisciplinary capstone course that attracts students from different engineering disciplines was revised to include a systems engineering focus. The multidisciplinary capstone course is structured to have design teams of three to five students work on client-sponsored design projects. In contrast to discipline-specific capstone courses, the multidisciplinary capstone is intended to have teams with students from three or more fields.

Using the existing framework of the multidisciplinary capstone course, the Penn State program introduced systems engineering by including eight modules that covered requirements analysis, systems thinking, systems engineering fundamentals, systems architecture, problem solving, verification and validation, project management, and decision and risk analysis. Each module consisted of readings, lectures, and hands-on applications. They introduced these modules in a sequence such that students could directly apply them to their design projects. For example, following the module on requirements analysis, students went through the requirements elicitation process to develop the system requirements for their projects. The multidisciplinary capstone design course was also restructured to follow a more traditional systems engineering lifecycle, going from mission statement, system requirements review, conceptual design review, preliminary design review, and finally, critical design review. Assessment results indicate that it is certainly feasible for undergraduate students in the traditional disciplines to gain an appreciation for systems engineering and be able to apply systems engineering principles in their capstone design projects.

The strategic goal of Auburn University's effort was to ignite interest among students in systems engineering, particularly among students who wished to learn more about securing computationally-intense systems used in national defense. To this end, Auburn University conducted two courses: an overview course and a hands-on project course. The intent of the overview course was to introduce students to the major concepts of systems engineering, illustrating those concepts with a case study of a system that required a secure

computing-intensive environment in which to operate. This course touched on all the systems engineering competencies to some degree, at a minimum making students aware of the competencies expected of them should they become systems engineers.

The second course (the hands-on project) required student teams to develop a prototype working solution that demonstrated secure communication using low-cost, low-power, open-source technologies. Each team was charged with assuming the role of a small business whose job was to come up with a system that met a real-world need within the DoD. Constraints placed on the teams were that (1) each system had to have a secure-communication component, (2) each system had to employ as much open-source hardware and software as possible, (3) the materials for each team could not exceed a given budget, and (4) each system had to have a "coolness" factor. The teams were evaluated on the viability of their solutions as well as their use of sound engineering practices to justify decisions.

The two-course sequence was conducted as an interdisciplinary effort between the Department of Computer Science and Software Engineering and the Department of Industrial and Systems Engineering. Both courses included undergraduate students, on-campus graduate students, and off-campus graduate students.

The Naval Postgraduate School (NPS) concept included two main ideas: the capstone provided an opportunity to vertically integrate the curriculum, and second, students were engaged in finding systems solutions in the problem area related to humanitarian assistance and disaster relief.

NPS requires both a thesis and a capstone project from its resident students. A curriculum team has worked over the last year to redesign the core systems engineering sequence to integrate the capstone project into the courses. Initial feedback is encouraging that this approach is increasing both effectiveness and efficiency. Two capstone teams have been working on the humanitarian-assistance and disaster-relief topic, due to be completed in September 2011.

NPS has launched a follow-on program for the 2011-12 academic year that involves both civilian and military institutions. The program focuses on strengthening students' learning in systems engineering and interest in careers in DoD on problems faced by the DoD, and on engaging new universities in the effort.

Acknowledgement

The author and members of this panel received financial support from the Office of the Assistant Secretary of Defense Research and Engineering. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the author and panelists and do not necessarily reflect the views of the sponsor.

Panel: The Graduate Reference Curriculum for Systems Engineering

Timothy L. J. Ferris, tim.ferris@incose.org

Moderator: Timothy L. J. Ferris, *University of South Australia*
Panelists: Peter Jackson, *Cornell University*; **Aaron Chia,** *National University of Singapore*; **Richard Freeman,** *US Air Force Center for Systems Engineering*; **Karl Geist,** *Gryphon Technologies*; **Stephen Cook,** *University of South Australia*

The Academic Forum panel concerning the Graduate Reference Curriculum for Systems Engineering (GRCSE, pronounced "Gracie") was moderated by Tim Ferris, with five speakers providing different perspectives on the content of GRCSE. The speakers were chosen because they represent diverse stakeholder positions, including education, as potential users of GRCSE, and the potential employers of graduates of systems engineering programs.

GRCSE is being developed as part of the BKCASE project (http://www.bkcase.org). The BKCASE project is developing a guide to the Systems Engineering Body of Knowledge, SEBOK, and GRCSE to clarify the nature of systems engineering and its many aspects, and to provide guidance for the education of aspiring systems engineers.

The goal of GRCSE is to provide useful guidance to universities to assist the development of professionally-oriented, systems-centric, master's-level programs in systems engineering. The guidance provided includes characteristics of the people who progress through the program in the form of (1) objectives, that is, the capabilities that graduates are expected to demonstrate three to five years after graduation; (2) outcomes, the knowledge and capabilities graduates are expected to have at the time of graduation; and (3) entrance expectations that enable a program to achieve the desired objectives. GRCSE also includes discussion of various student- and program-assessment strategies that should be considered in the process of program design, with the goal of ensuring that the graduates can attain the desired outcomes.

GRCSE provides a description of a curriculum architecture that conveys the concept of the intended curriculum. This curriculum dedicates about 50 percent of the time required to teach core topics and capabilities which all systems engineers should have and the additional capabilities which are needed by systems engineers in particular sub-areas of practice. The remaining 50 percent of the program time is available for universities to develop distinctive kinds or levels of attainment in their graduates. Associated with the curriculum architecture, GRCSE has a list of knowledge areas from the SEBOK that form the core section of the program, and in programs targeted at one of several focus fields of practice within systems engineering. The expected levels of attainment by students are described using