Integrating Systems Engineering and Systems Thinking into Undergraduate Engineering Education

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Abstract— **This panel will discuss the challenges of Integrating Systems Engineering Knowledge and Skills in Undergraduate Education, considering why we do this, what we include and examples of how we do it. The panel is based on work done by the INCOSE Academic Forum**

Keywords—Systems Engineering, Knowledge and Skills, Under Graduate

INTRODUCTION

The integration of systems thinking (ST) and systems engineering (SE) into the education for all engineers, including thoughts on how industry and academia can partner to achieve this objective, has been discussed at a number of Academic Forum meetings and conferences sponsored by the International Council on Systems Engineering (INCOSE) and other professional societies, such as the American Society for Engineering Education (ASEE).

One part of that discussion focuses on approaches for including more ST and SE content into undergraduate programs to improve the skills of all engineering students to help them deal with realistic, unbounded and complex problems; propose and select between holistic solution options; develop, build and test viable and robust solutions and to work with others in cross disciplinary teams.

The approaches to achieve this range from additional courses in ST and/or SE to educational materials and guest lectures that can be used by engineering faculty in their existing courses.

This panel will discuss the results of some of these discussions and plans to continue to explore approaches for introducing systems engineering to all future engineering students. We will consider what's been tried, how it is going, and what else we should be doing

PANEL FORMAT

The panel will consist of short positions statements from each panelist giving their view of the topic and identifying challenges and opportunities.

The floor will then be opened to questions and discussion with the audience. The panel chair will close the session with a report of the discussions and key takeaways.

POSITION STATEMENTS

A. Rick Adcock Cranfield University

The following theme emerged from a series of meetings on the role and scope of SE Knowledge and Skills in education, for both Systems Engineers and others:

To improve the use of Systems Engineering (SE) knowledge and skills in the University Education of all Engineering students, and to provide INCOSE products and services to enable this.

This theme was identified as one with a high value to INCOSE and broad interest within the community. It has sufficient scope to cover the practical and theoretical issues around SE education. Any work done against this theme will provide a starting point for tackling related SE education topics in the future. This aim will only be achieved through collaboration and partnering with others as part of a broader systems education agenda.

The background discussions which led to the selection of this goal as one part of the education strategy is provide in (INCOSE, 2015).

We need to describe and advocate WHY SE Knowledge has value in the education of all engineers; in a way which builds upon the language and needs of the engineering education community.

We need to define WHAT SE Knowledge is critical for the success of this work. We should include the principles of systems thinking for all engineers. However, this is not sufficient on its own and should be used as a foundation for other aspects of SE Knowledge related to both technical and life cycle activities. The SE Body of Knowledge (BKCASE, 2016) is a good baseline for this and will be discussed in more detail in the panel.

Finally, we must describe HOW SE knowledge can best be delivered to engineering students. There is much good work already around this topic. Gathering a better picture of this and beginning to share useful products from it should be done in parallel with creating new material.

Rick will present a brief overview of the results of a number of workshops on this topic, including some examples of current practice. Other panelist will give more detailed examples of particular examples.

B. Dr. Alice F. Squires Washington State University

Based on results from "Systems Education for All Engineer" workshops held in 2015, engineering faculty and systems engineering experts agree that systems education is important to all engineers, and that current undergraduate engineering education lacks systems education in key areas. Both faculty and experts also agree that system interactions, interfaces, and relationship among multi- is the primary system knowledge area, followed by system modeling and trade-off and decision analysis, that need to be addressed in the undergraduate engineering curriculum. The need for system knowledge in the areas of problem analysis (goals and objectives, needs statements, requirements elicitation), design and analysis (system architecture and analysis) and technical and project management (dealing with uncertainties and change), may be already covered in sufficient detail in the core areas of traditional undergraduate engineering education. Engineering faculty also chose system knowledge areas such as requirements analysis, understanding complexity, systems integration, and system science and fundamentals such as emergence and systems theory as important system knowledge area to address in undergraduate engineering education. A critical need was identified for training of engineering faculty in systems engineering concepts and principles, and for development and dissemination of systems engineering course material and resources that engineering faculty could use to teach system knowledge in the classroom. For 2016/17, we plan to hold workshops to extend this work, addressing the gaps in system knowledge and skills in undergraduate engineering education and ways that the systems engineering community can come together to address these gaps. Updated reports on our progress, new findings, and additional research in integrating system knowledge and skills into undergraduate engineering education over the past year will be presented as part of this panel. Additional work on building an educational pathway for the global engineer will also be included.

C. Dr. Peggy Brouse George Mason University

Systems thinking can arguably be thought of as making the systems engineering discipline different from other engineering disciplines. A system is not just breaking the different components into separate units and finding a solution for each. Some problems appear as a result of putting these components together. There has to be an understanding of the entire system. The system engineer is the visionary of the system and is expected to take this holistic view. In the past few years, ihis approach of systems thinking has also been considered an important skill for other engineering disciplines. Dr. Brouse will present the incorporation of a Principles of Engineering course in a non-systems engineering undergraduate degree. The discussion will be of how systems thinking is incorporated into the Cyber Security Engineering BS at George Mason University and why it is considered a mandatory skill. for this degree

D. Dr. Looft Worcester Polytechnic Institute

Systems Engineering (SE) principles are slowly being integrated into capstone design projects, both through direct inclusive approaches for local and national design competitions, as well as through direct capstone project advising and mentoring, and indirect focused course/curriculum offerings. Fred will describe an "engineering science" course developed specifically to address teaching essential SE topics, and including SE principles in capstone projects. This course, targeted at both third year students preparing for capstone projects, as well as first quarter seniors starting their capstone projects, was developed using an inverted classroom format where students viewed short videos and read key, topic specific papers and tutorials prior to class meetings, and then came to class where application specific problems were solved in engaging individual and team based settings. Fred will also present the motivation for this course, its structure/syllabus, a summary of course reviews, and recommendations based on how to improve the course, and similar courses, based on student input and first offering observations of what worked and could be improved in future offerings. Finally, student responses on the perceived value of including SE methods in capstone projects of all types, not just engineering, will be discussed.

E. Dr Mario Simoni Rose-Hulman Institute of Technology

The complexity of problems that engineers are being asked to solve is increasing rapidly. Effective solutions often require the integration of mechanical, electrical, computer software, chemical, and/or biological components. In order to manage this complexity, it is becoming important for all engineering students to learn how to approach the solutions to these problems using a systems perspective. In order to better motivate this approach to students we are introducing it within courses of their own engineering discipline. Mario will describe an approach adapting traditional systems engineering

concepts to create a framework of system models that can be introduced into courses of any engineering discipline at any level. Through the process of learning how to create these models, students gain an understanding of what is meant by a systems perspective and how this perspective can help them to solve problems.

PANEL MEMBERS

Rick Adcock has 20 years of experience in defence, working in industry, consultancy and academia. He joined Cranfield University at the Defence Academy of the UK in 2000 to help set up a Systems Engineering MSc to support MoD acquisition reforms. He has done research and published on Systems Engineering competencies, Network Enabled Capability (NEC), Enterprise Architecting and Model Based Systems Engineering (MBSE). He is currently engaged in doctoral research on Systems Engineering Competencies and Education.

Rick in Editor in chief of the BKCASE Project (www.BKCASE.org), which is creating a Body of Knowledge (and associate Reference master Curriculum) for Systems Engineering. He is also INCOSE Associate Director for education.

Dr. Alice F. Squires has over thirty years of technical and leadership experience. Prior to joining Washington State University in Fall 2014 as an Associate Professor, Dr. Squires served as Manager of Systems Engineering at Aurora Flight Sciences, Senior Researcher for the nationwide University Affiliated Research Center in Systems Engineering, Dr. Squires is a contributing author and editor to the Systems Engineering Body of Knowledge (sebokwiki.org) and the Graduate Reference Curriculum for Systems Engineering (bkcase.org/grcse). She is certified by PMI as a Project Management Professional, and by INCOSE as a Certified Systems Engineering Practitioner, including in Acquisition. She is a Senior Member of the IEEE, a member of and Director on the Systems Engineering Division board of the ASEE, a member of and co-chair of the Technical Planning Committee for the ASEM, and a member of NDIA, INCOSE, and PMI. Degrees earned include a BSEE from the University of Maryland; a MBA from George Mason University; and a Ph.D. in Systems Engineering from the Stevens Institute of Technology. Her areas of expertise include Engineering Management, Systems Engineering, Technical Management, Project Management, Systems Thinking, Online Education, and Engineering Education.

Dr. Peggy Brouse has over forty years of practical and academic experience in Systems Engineering. She is an associate professor in the Systems Engineering and Operations Research department at George Mason University. Dr. Brouse is the Director of the Cyber Security Engineering program. She is also the Director of Distance Education for the Volgenau School of Engineering. She designed the Mason undergraduate program in Systems Engineering over 20 years ago. Before Mason, Dr. Brouse worked as a Program Director at the MITRE Corporation where she managed projects for NIH, USDA and the US Navy. At CACI, she was a database analyst for EPA, and the U.S. Geological Survey. At the U.S. Army Computer Systems Command, she was a Systems Analyst, and Programmer for the Army Civilian Payroll System (STARCIPS). Dr. Brouse is a member of the IEEE and INCOSE. Within INCOSE, she served as the director of the Academic Forum. Degrees earned include a BS in Computer Science from the American University; MBA from Marymount University; and a Ph.D. in Information Technology and Engineering from George Mason University. Her areas of expertise include Systems Engineering, Requirements Engineering, Cyber Security Engineering, Online Education and Systems Management.

Dr. Looft is the Academic Director of the WPI Systems Engineering Program and has been an Electrical and Computer Engineering (ECE) faculty member for more than 35 years. His most recent academic interests include projects-based education, systems engineering applications to projects based education, solar and alternative energy systems design and development, and robot systems.

Throughout his career, Dr. Looft has had an interest in global project center student advising, a concept unique to WPI and described on the WPI Projects Program web site, and particularly the WPI Global Projects Program. He has been an on-site project advisor at numerous centers, including Washington DC, London England, Venice Italy, San Juan Puerto Rico, Capetown South Africa (two weeks) followed by Windhoek Namibia (7 weeks), Copenhagen Denmark, Nantucket, and in Greenbelt Maryland for the Goddard Space Flight Center Projects Program (8 years).

Dr. Looft received his Ph.D. in Electrical Engineering in 1979, a Master of Science in Computer, Information and Controls Engineering in 1976, an MS in EE in 1975 and a BS in EE in 1973, all from the University of Michigan (UM, Ann Arbor). Dr. Looft is a Senior Member of the IEEE and a member of INCOSE.

Dr Mario Simoni is Department Chair and Professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology in Terre Haute, Indiana in the USA. He earned his Ph.D. in Electrical Engineering from the Georgia Institute of Technology in Atlanta, Georgia in the USA in 2002. His research interests include integrated circuit design, modeling of neural systems, and improving capstone design experiences for undergraduate engineering students through the introduction of systems engineering concepts. He began his interest in systems engineering when teaching the capstone design course in the Electrical Engineering Department in the 2009-2010 academic year. He worked under the tutelage of Bill Schindel for a couple of years while developing materials for the capstone course, and since then, has continually been revising materials and techniques. In addition to the introduction of systems concepts into capstone design he has been involved in 3 workshops to over 60 faculty in many different disciplines to help them understand some of the basic systems concepts and how to help students learn these concepts. He is a new member of INCOSE and this is his first time attending the International Symposium**.**

ACKNOWLEDGMENT

The INCOSE academic forum is a network of engineering educators who share a belief and passion in the role of SE knowledge and skills in the education of all engineers.

We would like to thank all those who have contributed to our forum events.

REFERENCES

[1] BKCASE Editorial Board. 2015. The Guide to the Systems Engineering Body of Knowledge (SEBoK), v. 1.4. R.D. Adcock (EIC). Hoboken, NJ: The Trustees of the Stevens Institute of Technology. Accessed 11 Aug 2015. www.sebokwiki.org.

[2] Rick Adcock. 2016. Integrating Systems Engineering knowledge into the education of all engineers, research challenges. CSER 2016

[3] Mario Simoni, Eva Andrijcic, Bill Kline, Ashley Bernal. 2016. Helping Undergraduate Students of any Engineering Discipline Develop a Systems Perspective. INCOSE Symposium 2016.

[4] 1 May 2015 WPI workshop website at http://www.wpi.edu/research/seli/incose61.html.

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