A Student's Perspective on the Education of Systems Engineers

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Abstract. The education of systems engineers is a main focus of the International Council on Systems Engineering (INCOSE). INCOSE released its latest guidance via the Systems Engineering (SE) Vision 2020 which describes the need for an increase in several aspects of systems engineering including how we educate systems engineers. Being a current graduate student of systems engineering provides me with unique insights into this process. To augment my academic experience, I also bring several years of experience in the military defense industry. This paper presents my experience through multiple perspectives, while analyzing the current curriculum for systems engineering education. The main lesson learned is that the study of systems engineering is a journey and not a destination.

Introduction

In July 2008, the International Council on Systems Engineering (INCOSE) became a member society of the Accreditation Board for Engineering and Technology (ABET). INCOSE will have responsibility as one of the leading societies for systems engineering programs. This means INCOSE is one of the main accreditation authorities for all systems engineering programs within the United States.

This paper describes the INCOSE guidelines for incorporating systems engineering into graduate curriculum; in addition I also discuss the need for an introduction to systems engineering at the undergraduate level of studies. The inclusion of systems engineering fundamentals or the introduction of systems engineering methodologies to the capstone classes of an ABET accredited program would greatly augment the development of a well-rounded engineer.

I first describe INCOSE's position on educating systems engineers by briefly discussing the Systems Engineering (SE) Vision 2020. Following this, I provide an overview of my experience in both education and industry with a focus on how an introduction into systems engineering would have benefited me. Following my experience, I offer several lessons learned and recommendations. I close the paper with my conclusion on a student's perspective on the education of systems engineers.

Background

I recently received my Bachelor of Science degree in Electrical Engineering (BSEE) and am currently attending classes to obtain a Masters of Science degree in Systems Engineering (MSSE), which provides me with unique insights into the process of educating engineers. After reading the SE Vision 2020, a document which was developed to enhance several aspects of the field over the next ten years, I decided to write this paper detailing my opinions on the education of systems engineers. Having over fifteen years of experience in the military defense industry, I can provide a glimpse into industry and how systems engineering is a subject which is often overlooked. During my time in industry I have met numerous engineers and project managers and have benefited greatly from their knowledge and experience.

Educating Systems Engineers

As stated in the SE Vision 2020, masters programs are increasing rapidly. I briefly describe the finding on systems engineering education provided in SE Vision 2020. The framework of the SE Vision 2020 was to analyze the current state of practice and trends in systems engineering. It further developed a set of drivers and inhibitors that would influence the future state [Haskins 2007, 7]. This is shown in figure 1. The current state of systems engineering education can be boiled down to an understanding that systems engineering is considered a graduate level course of study. Most undergraduate coursework is specialized with a very limited amount of program management, which is being introduced during the capstone design courses only. A systems engineer is described as one having a depth in systems engineering and an educational knowledge in a technical area with an additional understanding of program management [Haskins 2007, 17]. To develop a systems engineer of this kind, we must instil systems thinking and systems engineering into all aspects of engineering curriculum and it must be started early in the educational process. Currently, systems thinking and limited systems engineering principles are starting to be introduced to undergraduate students.

Area	Drivers	Inhibitors
• SE Education	• Emergence of awareness of need to inculcate systems thinking at earlier stages in individual educational experiences • Increasing ability to educate at a distance, providing the global classroom at home • Increasing need to provide capability to instill transdisciplinarity in engineering education	• Lack of incorporation of systems thinking in classical engineering • Lack of an overarching vision or guiding framework for research • Lagging posture of education curricula • Inadequate production rate of system thinkers • Challenge of educating old management in new concepts

Figure 1. SE Education drivers and inhibitors affecting the practice of systems engineering

In the previous figure you can see the list of drivers that must be exploited and inhibitors that must be mitigated if we are to successfully meet SE Vision 2020. We must encourage academia to introduce systems thinking early on by focusing on the creation of systems and not individual class projects. We must create commonality in coursework so that a student builds upon not only

analytic concepts but also on systems thinking. We must diversify the education of systems engineering to include other universities and colleges. For example, the College of Engineering and the College of Business Administration could collaborate in such a way that basic engineering management classes could be offered and available as an elective course to undergraduate engineering students. These courses could be taught not only by professors, but also by representatives from industry who could be guest lecturers. Figure 2 illustrates systems engineering needs as they relate to the drivers identified by SE Vision 2020. To attain this vision, we must spotlight the needs of systems engineering education and maximize the current initiative to develop a system-thinking engineering student.

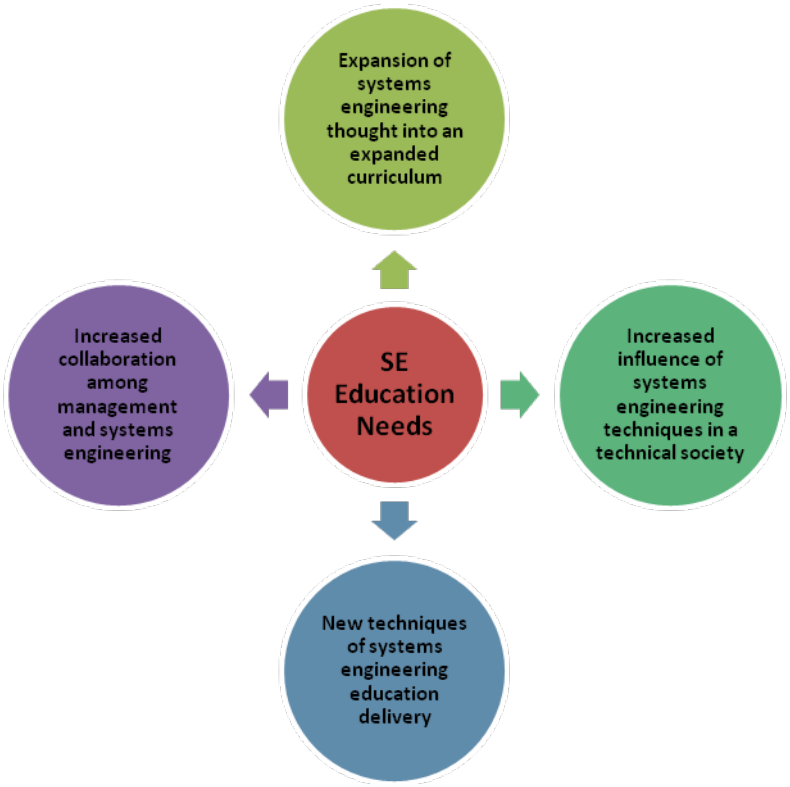

Figure 2. SE Vision 2020 needs that must be reached in educating systems engineers

In figure 3, you can see the goals which must be achieved to properly fulfill SE Vision 2020. It shows the success of these goals is based on the synergistic relationship between academia, professional societies and industry. Organizations such as INCOSE must look to student chapters as an avenue to influence change such that they can “prepare the battlefield” and align the goals set forth in SE Vision 2020 with the university’s strategic plan.

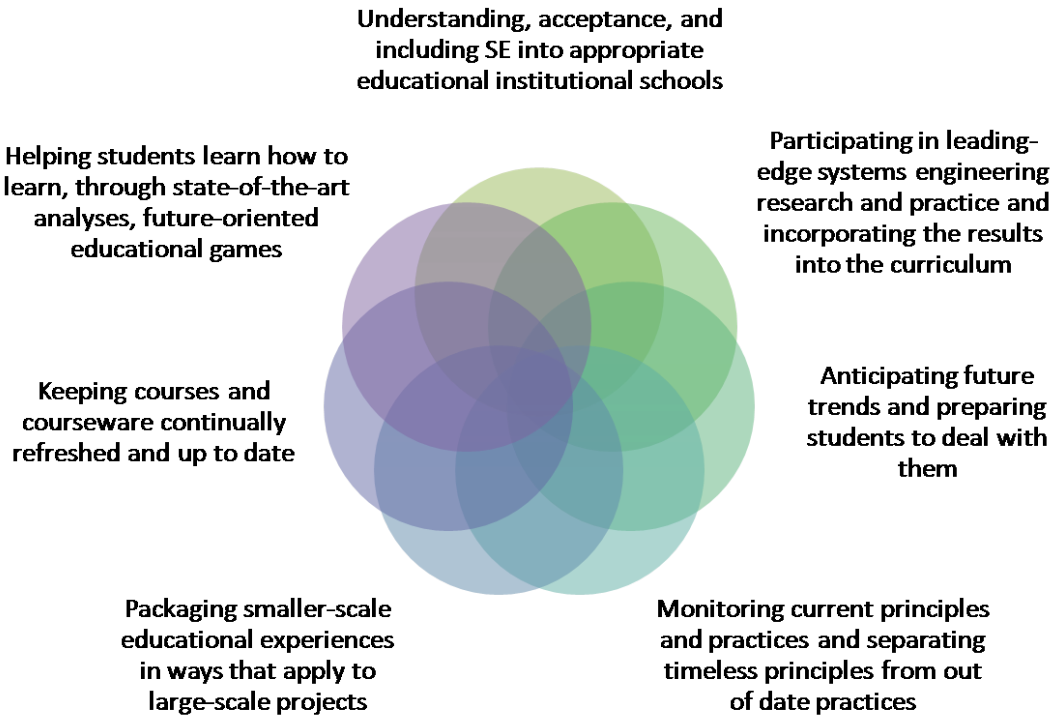

Figure 3. Systems engineering education goals to arrive at SE Vision 2020

To reach these objectives we must concentrate on collaborating with all aspects of systems thinking and systems engineering. As industry is the recipient of new engineers, we must include them into the development of new education curriculum. If we do not meet the needs of industry, then industry will be forced to develop training innovations, such as the certificates of systems engineering offered by some companies.

Experience

As I look back on my academic and work experience, I see that an introduction to systems thinking would have enabled me to affect change early on, especially in a particular project. I would have possibly been able to refocus the project, which did not start with a systems engineering approach, saving time and money for the stakeholders.

In the following sections I will illustrate my experience in academia and industry. After discussing those two topics I will provide my lessons learned as it relates to educating systems engineers. Then I will pose recommendations for aligning an undergraduate program to address the main points of the SE Vision 2020. I will then take a quick look into graduate studies focusing on enhancing the symbiotic relationship between academia and industry.

Academic Experience

I started the University of Texas at El Paso (UTEP) Electrical Engineering undergraduate program as a non-traditional student. After working in the military defense contracting industry for almost ten years, I then decided to return to school to finish my undergraduate degree. During my work experience I had met some very interesting individuals who set me on the course to wanting to

become an engineer. My previous work experience had also introduced me to project and contract management. I had worked my way up through the company and literally started in the mailroom. I had worked on proposal teams, learning how a company shapes responses to a Request for Proposal (RFP). But I wanted a more technical job. I wanted to be an engineer.

During school I found myself outside of my peer group. I was the older student in a classroom full of more traditional four year degree students. But my years of work experience gave me an advantage. I was able to apply my previous experience to my engineering education. I felt I was prepared to undertake my undergraduate education, but as I started my senior project, I realized that the engineering elements of the project were not as difficult as the technical management of the project.

Senior project is a capstone class broken up into two semesters. The first semester was a design and development phase and the second semester was a build and test phase. The two semester class focused on creating a project which utilized a microprocessor and required a data flow from input to output. The descriptions of the courses are below:

- EE4220 Senior Project Laboratory I. Research and analysis leading to a preliminary design for an approved engineering project. Includes formal project proposal and work plan; specification of functional, performance and cost goals; generation of computer-aided design documents and simulation or modeling results.
- EE 4230 Senior Project Laboratory II. The senior project design process is concluded through prototyping, testing, and revisions.

My idea of senior project was to obtain a corporate sponsor and develop a project with an industry focus. The senior project professors thought it was a great idea. I started contacting local businesses hoping to find a company willing to invest time and resources to sponsor a senior project. The senior project teams were composed of electrical engineering students who started Senior Project Laboratory I during the first semester of their senior year. This meant they had completed the core electrical engineering courses and only lacked the elective or concentration coursework. In the UTEP Electrical Engineering program you could choose one of four concentrations. The four concentrations were: computer engineering, fields and devices, systems and communications, and general. My team was composed of two computer engineering students, one devices student and one communications student.

We found a sponsor from industry and met with the engineering team about a suitable senior project. We were asked to revise a current product to include an additional interface. In retrospect, we should have asked to develop a new prototype device and not modify an existing design. The redesign included a layer of difficulty that we, as students, did not need. We had to integrate new code with legacy software code and build onto a device that had undergone years of development.

The first semester was misleadingly uneventful because we were unfamiliar any systemic method of project management or systems engineering. We focused on the design of the project without grasping the true meaning of the design process. We were required to create a Gantt chart to track our schedule as a part of the project management but our lack of systems engineering forced us to incorrectly estimate resources in particular the time necessary to complete the project. Because of this, we were constantly behind schedule.

We met the course goals and continued onto the next semester. During the second semester, we developed the redesign and built a device which was a modified prototype. In the end, the project

was completed successfully and we were able to verify the data flow through the redesigned system.

Industry Experience

My first job after graduation was serving as a liaison between two organizations designing a new training system. I was tasked to provide the interface between the customer and the developer whose experience was in the computer gaming industry. This role was new to me and I struggled to keep a handle on the development of the project. Our part of the project was to assist the developers by providing information which utilized our military subject matter expertise and engineering mindset. We were not asked to improve the development process used to create the system but only to assist in the understanding of the military material by all involved. We provided the technical expertise on the overarching concepts to the project but had no influence on the development of the design.

If I had more of a background in systems engineering, I feel I could have positively impacted the project by being proactive in the progress of the initial design. I could have provided my systems engineering knowledge to the design of the systems and possibly shown the need for a fulltime systems engineering professional to be assigned early on. Instead, the project lacked that much needed systems thinking approach. Throughout the systems' development it faced several redesigns which caused countless delays.

This project was developed in a unique way. The technology to be utilized was proven to help in the training of cognitive thinking skills, and it had a very successful implementation in several other projects. It was a blend of virtual reality and hardware mock-ups to immerse the trainee into an environment similar to the actual one. But utilizing this method meant the developer had to take the new concepts and try to shoehorn them into the training environment previously developed. The initial project plans were designed by the developer and then the developer told the customer what they needed. The developer incorrectly formulated the user's requirements and then developed a preliminary design based on those requirements.

During the kick-off meeting the developer presented a preliminary design to the customers. This was the first time some of the audience had seen or heard about the project and they were effectively being given an answer to a question they hadn't asked. As I was new to engineering and had no systems engineering training, I saw nothing wrong with this approach and neither did anybody else. But in hindsight this was the start to a very troubled project.

Lessons Learned

I have learned that there is no substitute for an education in systems engineering. The concepts taught by our universities are invaluable but must be introduced earlier in the educational process so that the ideas are advanced along with the basic engineering fundamentals. Experience alone will not produce a good systems engineer. It will take a combination of education, experience and mentoring.

I have also realized that systems engineering is often an overlooked component in industry. Most project and program managers are unaware of the benefits of making systems engineering a focus early in the design. Industry is focused on the bottom line, meaning a systems engineer is a resource which, when applied early, can have a positive influence on the profit margin.

Recommendations

The subsequent recommendations summarize my ideas to introduce systems thinking into undergraduate coursework and create a renewed relationship with industry to develop the systems engineers needed to meet SE Vision 2020. As previously stated, we must infuse academia with industry exposure, and thus change the way we educate systems engineers. By fostering a relationship with industry, an undergraduate curriculum can benefit by soliciting industry for guest lecturers. These practitioners can provide the students with an exceptional overview of industry and an insight into how industry employs a peculiar engineering concept. I believe the use of subject matter experts would increase a student's retention of the material by providing real world examples. This concept of guest lecturers should be introduced from start to finish in all aspects of engineering education.

If systems engineering cannot be introduced during undergraduate studies, let us consider an alternative solution. According to ABET Criterion 3 program outcomes (d), a program must demonstrate that their students have attained an ability to function on multidisciplinary teams [EAC Criteria, 2009, 2]. I believe undergraduate engineering students would benefit from a cross-discipline capstone senior project. If a university's College of Engineering can coordinate between departments to develop a capstone senior project that utilizes a multi-discipline approach, then I believe the students involved would greatly increase their understanding of working within a diverse team.

In the perfect situation, a university's engineering program would develop a capstone project which includes a multidisciplinary team, a systems engineering graduate student and an industry partner. This industry focused project can be developed so that each student's abilities would be taxed equally. The graduate student of systems engineering would be responsible for leading the team from start to finish by advising and using sound systems engineering processes. The industry partner would act as a mentor to provide the guidance and to serve as the project stakeholder.

These complex interactions promote the type of transformation necessary to elevate an undergraduate student from comprehension to developing the capability needed to practice engineering. The educational process needs a mechanism to effectively immerse the student into the environment that will enable them to make that transition. I believe a project that has been developed using the ABET Criterion 3 and SE Vision 2020 can provide that situation. An undergraduate student with little to no work experience would benefit from a capstone project with an industry "look and feel." The project should be structured with very strict guideline at first allowing the students to learn the process. Later as the teams develop, the course work can change from a classroom to a laboratory environment.

This collaboration between academia and industry can bring real world engineering to the classroom. INCOSE is driving education to infuse systems thinking into more academic disciplines. The challenge is to provide systems engineering education and training that integrates the best systems engineering practice with the traditional academic disciplinary engineering approaches [Sage 2006, 2].

Industry and academia must promote and fund programs that provide educational opportunities that advance students from apprentice to journeyman during the post undergraduate phase. This would include the development of mentoring relationships between entry level engineers and seasoned professionals. Academia provides the student with a toolbox of engineering concepts but

a new engineer might not know the right tool to use. A mentor could guide the new engineer to make good decisions and promote good engineering practice.

Conclusion

Do systems engineering concepts belong in an undergraduate program? I think the fundamentals and program management aspects, at the very least, should be included into the curriculum. I believe engineering students would benefit greatly from an introductory course in systems engineering prior to, or concurrent with, the capstone senior project classes. At the minimum, the undergraduate curriculum should be changed to include some sort of systems thinking into each course.

For me, I am at a crossroads. I must complete my graduate coursework mindful that the way we educate systems engineers is changing. I am aware that industry has a need for well-rounded systems engineers with a focus on seeing the big picture. The study of systems engineering is a journey and not a destination. I will try to instill systems thinking into my peers, and with my connection to industry I will endeavor to bridge the gap between academia and industry. This means reaching out to professional societies such as INCOSE and becoming involved in developing policy that has a positive result on systems engineering education. I believe that industry must use professional societies as a channel for the continuing improvement of both the ability and discipline of educating engineers.

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BIOGRAPHY

Juan C. Calderon has over fifteen years experience in the military defense contracting industry during which time his responsibilities have ranged from those of Administrative Assistant to Engineer. Juan C. Calderon earned a Bachelor of Science degree in Electrical Engineering in 2006 from the University of Texas at El Paso (UTEP) and is currently pursuing a Masters of Science degree in Systems Engineering at UTEP. He is a student member of the Institute of Electrical and Electronics Engineers (IEEE) and of the Enchantment Chapter of International Council on Systems Engineering (INCOSE).