AC 2011-1077: SE CAPSTONE: INTRODUCTION OF SYSTEMS ENGINEERING INTO AN UNDERGRADUATE MULTIDISCIPLINARY CAPSTONE COURSE

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Liz holds a B.S. degree in Electrical Engineering from Penn State (1979), and M.S.E.E. degrees from Massachusetts Institute of Technology (1981) and The Johns Hopkins University (1988). She worked in industry for 11 years with a defense contractor (HRB Systems/Raytheon), and then co-founded and worked for five years with a high-tech startup (Paragon Technology), which developed digital video add-in cards/modules for laptop and rugged portable computers. Since joining Penn State in 1999, Liz has taught design courses in the Mechanical, Electrical, and Civil and Environmental Engineering Departments, and in SEDTAPP. In 2001, she became director of the Problem-Based Learning in Entrepreneurship project (underwritten by the GE Fund), and in 2002 was named Director of the Engineering Entrepreneurship Minor. As of Fall 2009, the E-SHIP Minor has 204 graduates representing many majors: 60% are from engineering, 25% from business, 10% from Information Sciences and Technology, and 5% from other majors. She was awarded the 2005 Price Foundation Innovative Entrepreneurship Educators Award Stanford University REE Conference (Roundtable for Entrepreneurship Education) and 2006 ASEE Kauffman Outstanding Entrepreneurship Educator Award. In January 2010, Liz stepped down as Director of the E-SHIP Minor to help define expansion plans for undergraduate entrepreneurship education across Penn State. Liz is co-Director of the Lion Launch Pad, a new student-centric on-campus business incubator. Liz is also involved in NSF-funded research, supporting both PFI and IEECI grants, and is the incoming Program Chair for the ASEE Entrepreneurship Division (2010-2011).

Since 2006, Liz has been involved in developing the ASME Innovation Showcase (I-Show), which provides a platform for top collegiate student teams to compete for seed money and attend 4-day business start-up workshops with the goal to commercialize their product idea. In the three I-Show events conducted in the last three years, 24 teams have competed with $74,000 in seed capital funds awarded.

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SE CAPSTONE: Introduction of Systems Engineering into an Undergraduate Multidisciplinary Capstone Course

Introduction

Among the major concerns for the systems engineering profession is "the lack of quantity and quality of systems engineering expertise to meet the demands of the government and defense industry," according to the July 2006 National Defense Industrial Association task force report.[1] Addressing this lack of expertise requires a multi-faceted approach and, while the lack of systems engineering expertise cannot be addressed by universities alone, the role of universities in training the next generation of systems engineers is critical.

The number of engineering undergraduates with degrees in systems engineering is quite small, given that only 11 institutions offer bachelor's programs in the field as of 2007.[2] Entry level systems engineers, therefore, usually have degrees in traditional engineering domains, including mechanical engineering, aerospace engineering, and electrical engineering. The number of institutions awarding bachelor's degrees in systems engineering is unlikely to grow significantly in the next decade because of financial pressures on institutions and the time needed to address accreditation issues. Thus the increasing demand for systems engineers cannot be met with graduates in the systems engineering field at the undergraduate level alone. While significantly more institutions offer master's level programs in systems engineering (27 as of 2007), many of the students in these programs are part-time students who work full time, often as systems engineers. Therefore, while master's level programs help to address the quality of systems engineering expertise, they do not mitigate the quantity issue, as they don't provide a means to increase the pool of students attracted to the field. In order to address the quantity of systems engineering expertise, it is necessary to expose undergraduate students in the more traditional engineering fields to systems engineering fundamentals and allow them to apply those fundamentals in a meaningful way. The International Council on Systems Engineering (INCOSE) in its vision for systems engineering in 2020[3] is cognizant of this need and recommends the insertion of systems engineering principles into traditional engineering disciplines such that "systems thinking and systems engineering will permeate both undergraduate and graduate programs."

The Pennsylvania State University has undergraduate degree programs in a wide range of traditional engineering disciplines including aerospace, chemical, civil, mechanical, electrical, and industrial engineering with total engineering undergraduate enrollment exceeding 7000. Penn State's College of Engineering is ranked in the top 25 and annually ranks among the top schools in numbers of B.S. graduates (1327 in 2008, 2nd in the U.S.). However, most of these students receive little exposure to systems engineering, nor have an opportunity to apply its fundamental principles.

In this paper we report on our efforts in fall semester 2010 to introduce system engineering fundamentals to students from the traditional engineering disciplines through an existing senior-level multidisciplinary capstone course, *Interdisciplinary Capstone Design Project (ICDP)*. The course is open to students from biomedical engineering, chemical engineering, computer engineering, electrical engineering, mechanical engineering, and industrial engineering. While all engineering students at The Pennsylvania State University complete a capstone design course, most students complete a discipline-specific capstone. An interdisciplinary design course that meets ABET criteria for the engineering majors listed above has been developed by Penn State to allow students to work on multidisciplinary, innovative design. This course, therefore, serves as an ideal test bed for the introduction of systems engineering into a senior capstone design course. Teams apply fundamental design and analysis methods to open-ended engineering problems, working in teams of three-to-five students.

The approach used for this the project was to introduce system engineering concepts, in a just-in-time (JIT) manner, into the capstone course, have students apply those concepts during the design process, and provide deliverables consistent with the systems engineering project life cycle. Assessment methods have been established to determine the effectiveness of this approach for improving students' knowledge and understanding of systems engineering.

Learning Objectives and Approach

The broad objective of this project was to increase awareness of systems engineering concepts and systems engineering as a profession for students with little or no previous exposure to systems engineering. Specifically, at the end of the course it was intended that students should

- Understand what systems engineering is
- Understand what systems engineers do
- Understand the qualities and skills that systems engineers bring to projects
- Develop and practice the skills of systems engineers
- Understand how systems engineers think (analytic skills)
- Consider a career in systems engineering

To reach these objectives, the approach taken was to introduce students to systems engineering principles through the delivery of course modules covering systems engineering topics, while concurrently having students apply these principles to their design projects. The modules were developed and delivered by faculty who teach in The Pennsylvania State University's Master of Engineering in Systems Engineering program from the School of Graduate Professional Studies in conjunction with faculty from the College of Engineering. The modules with their respective objectives are listed in Table 1. One module was delivered in each of the first 8 weeks of the course, which met twice per week. Each systems engineering module consisted of readings, exercises, and a 75-minute class presentation. During class meetings when modules were not delivered, students met in their teams to work on their projects. Each team had biweekly conference calls with project sponsors. Teams were also expected to deliver functional prototypes as well as end of semester posters and a final presentation. Students had numerous deliverables during the semester, many of which were intended to align with those of the systems engineering design lifecycle. The course modules and deliverables are shown in Figure 1.

Table 1 Systems Engineering Modules with Learning Objectives

Module	Module Learning Objectives
System Engineering Fundamentals	1. Students will describe how systems engineering adds value to the development of complex projects. 2. Students will articulate some common systems engineering process models and show how they are related. 3. Students will summarize the fundamental methods of systems engineering in the context of their specific design project.
Systems Requirements Analysis	1. Students will develop system requirements from stakeholders needs. 2. Students will write requirements that are achievable, verifiable, and unambiguous. 3. Students will develop requirements that define the 'need' without specifying the 'how'.
Systems Thinking	1. Students will correctly articulate the fallacy of reductionism within the context of their projects. 2. Students will recognize the interdependency of system components and provide concrete examples of emergence.
Systems Architecture	1. The student can describe what architecture is. 2. The student can identify architecturally significant requirements and create architecture of a system using them. 3. The student can describe tactics and patterns used in creating an architecture of a system.
Problem Solving	1. Students will correctly define and provide examples of the key components and variables of problem solving. 2. Students will accurately explain the value of different problem solving levels and styles in designing engineering systems. 3. Students will identify benefits and challenges of designing systems with diverse problem solvers.
Systems Engineering Project Management	1. Students will correctly identify the relationship between work-breakdown, task estimation, and scheduling. 2. Students will apply general management competencies to their projects.
System Verification and Validation	1. Students will distinguish between verification and validation concepts clearly through examples of system verification and validation. 2. Students will describe verification planning and verification process in context with the system development lifecycle. 3. Given a verification requirement statement, students will determine the correct type of verification method; test, demonstration, analysis or inspection. 4. Given a list of requirements for a system development project, students will construct a verification matrix.
Decision and Risk Analysis	1. Define and understand risk and opportunity in the decision making process. 2. Understand the decision making process and identify the factors contribute to the process in the context of engineering decision sciences. 3. Generate alternatives and select the best decision using all the available information.

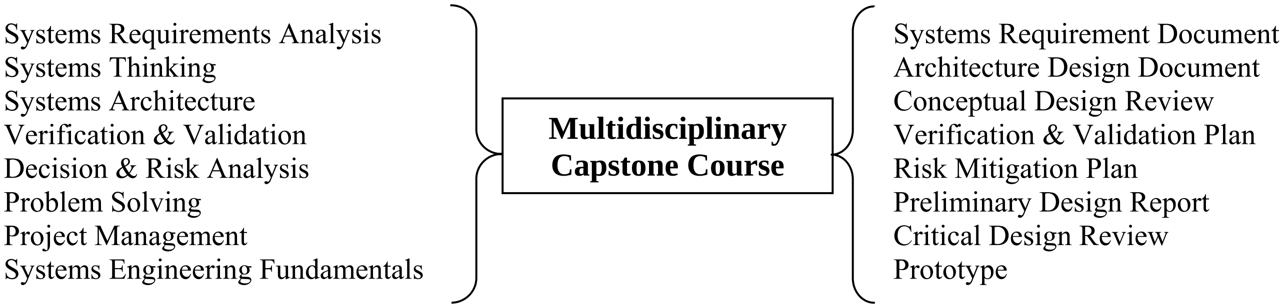

Figure 1 Multidisciplinary capstone showing SE input modules along with student deliverables

Course Organization and Projects

The interdisciplinary capstone design course is a one-semester course open to students in biomedical engineering, computer engineering, electrical engineering, mechanical engineering, and industrial engineering. Students may choose to take the multidisciplinary capstone design course or choose to take a capstone course offered by the individual departments. Students choose the capstone course at the start of the semester at a project kickoff after viewing the potential projects offered in the different capstone courses. Thus, having a project with appeal to students interested in multidisciplinary design was essential.

The project offered to students in the interdisciplinary capstone class was sponsored by the Department of Defense, and provided students an opportunity to apply their knowledge to a realistic systems engineering problem. The problems are described as follows:

"In March 2010, the Office of the Secretary of Defense (OSD), US Southern Command (USSOUTHCOM), and the National Defense University (NDU) partnered to form the PEAK (Pre-positioned Expeditionary Assistance Kits) JCTD (Joint Capability Technology Demonstration) to address the following **problem statement:** *USSOUTHCOM's capability for promoting security and enhancing stability within its geographic area of responsibility is constrained by a limited capacity for enabling scalable critical services during time-sensitive events.* Authorities often lack the capacity to develop or repair essential services in times of man-made or natural disasters, particularly in providing clean water, power, local situational awareness (LSA) and communications during the first days of crisis."[4]

The project had clear multidisciplinary aspects and is representative of a complex system. In addition, its focus on providing humanitarian assistance was appealing to students. Seventeen students registered for the course based on interest in the project. Given the project description and class size, the PEAK system was broken down into four major subsystems with teams of 4–5 students responsible for each subsystem. The interdependency and interaction between each of the subsystems established the need for system integration and substantial interaction and coordination between student teams. The breakdown of the system into subsystems showing the composition of student teams is shown in Figure 2. The systems design process follows the classical ‘vee’ process model[5] shown in Figure 3 up to the point of prototype development. It is important to note that the SE Modules listed in Figure 1 were scheduled close in time to implementation of the corresponding step in the design process (the JIT approach), i.e., the requirements analysis module was delivered early in the course for students to develop the System Requirements Document (SRD); the architecture module was delivered prior to the conceptual design review, etc. An important first step for students was to translate the stakeholder expectations given in the following into system requirements:

The system must have the following attributes:[4]

- Utilizes commercial-off-the-shelf (COTS) technology with limited development
- Easy to operate and train
- Low maintenance and sustainment requirements and costs
- Exportable to foreign nations
- Non-proprietary existing technology
- Light weight (man portable)
- Durable and weather resistant
- Limited HAZMAT requirements
- Transportable by military and civilian air, sea, and land modes
- Completed kit and consumables must fit on a single 463L Cargo Air Pallet

Water purification equipment with the capability to produce potable water from fresh, brackish, and salt water:

- Includes filtration system, distribution capability, and storage container
- Provides potable water for drinking and hygiene
- Powered through the kit Power Generation Subsystem

Reliable power from primarily renewable sources for PEAK (water purification, communications, and situational awareness capabilities):

- Provides power to the components of the kit
- Power is generated through renewable resources (solar, wind, etc.) with a fossil fuel generator backup
- Has sufficient capacity to support all components of the kit simultaneously

Local situational awareness and information sharing on threats, local populace, services, environment, infrastructure, and other support personnel to enable first responders and decision makers to respond effectively to a time-sensitive event:

- Unmanned Aerial System (UAS), control device, camera (still or motion), and platform to view images
- Integrates with System
- Power through the kit Power Generation Subsystem

Local, national/regional, and international communication to transmit/receive voice, data, and images:

- Consists of a communication device that transmits voice and data over a low bandwidth network
- Enables personnel to communicate situation reports with authorities and other aid personnel
- Integrates with situational awareness component of the kit
- Powered through the kit Power Generation Subsystem

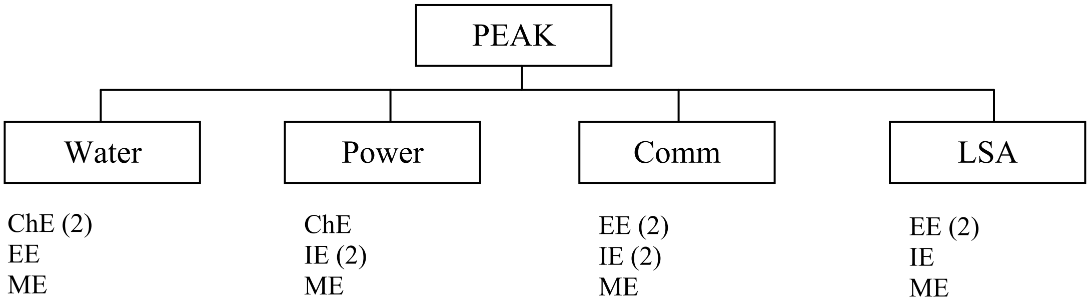

Figure 2 Subsystems of the PEAK showing discipline breakdown of student teams

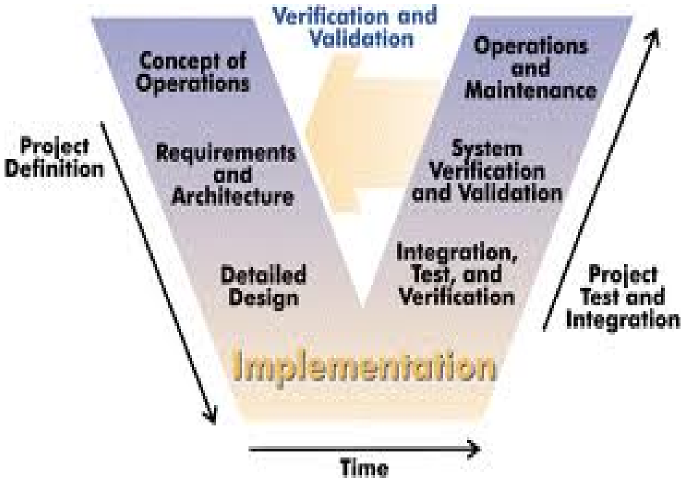

Figure 3 Vee process model[5] followed by student teams

Assessment Methodology

A survey was designed to assess general systems engineering knowledge and was administered to the students at two time points: the beginning and the end of the fall 2010 semester. These time points were selected such that the students had not received formal systems engineering instruction in class prior to the first time point and systems engineering instruction had been completed before the second time point. The pre- and post-surveys contained the same items such that baseline knowledge could be determined, and the responses could be compared across the two time points, thus allowing for the evaluation of potential systems engineering knowledge changes. Such assessment was critical in determining whether the selected approach to meet the learning objectives was successful, particularly since this was the first offering of a systems engineering interdisciplinary design course for undergraduate students at The Pennsylvania State University. In both the pre- and post-survey, students were asked to rate their level of agreement to a series of systems engineering concept questions, as well as to indicate their confidence level for each response. The pre- and post-survey served as summative assessment of the students' systems engineering knowledge.

While a repeated measures *t*-test was not conducted on the data due to sample size limitations, differences between time points, based on descriptive statistics and frequencies, were critically analyzed for patterns and changes over time. The survey items, along with descriptive statistics and frequency data for each item, can be found in Appendices A and B. It should be noted that items 3, 4, 7, 8, 9, and 10 were reverse coded such that the correct answer is *disagree* or *strongly disagree*, not *agree* or *strongly agree*. This was designed to control for response sets (i.e., the tendency for the student to respond systematically to items without considering item content).

The pre-survey was completed by 17 of the 17 students (100%) enrolled in the systems engineering interdisciplinary design course. The post-survey was completed by 14 of the 17 (82%) students enrolled. Students' consent to use the pre- and post-survey data was obtained as per the policies of the University's Office of Research Protection. The results and findings of the pre- and post-survey assessing general systems engineering knowledge follows.

Assessment of Systems Engineering Knowledge, Pre- and Post-Course

The majority of the students' responses provide indication that the students did learn systems engineering concepts from the course. Approximately 71% of the students strongly agreed post-survey that "the application of systems engineering process models is a fundamental aspect of systems engineering," which is an increase of roughly 24 percentage points in strongly agree responses from the pre- to post-survey (item 1). Also, 100% of the students who responded post-survey were very confident in their answer to item 1, which is in contrast to only 41.2% pre-survey. This change represents an increase of roughly 60 percentage points across the two time points. Almost exactly the same pattern of pre-survey ($\mu = 4.24$) and post-survey ($\mu = 4.79$) agreement levels, and pre-survey ($\mu = 3.12$) and post-survey ($\mu = 4.00$) confidence levels were found for the responses to item 2, "The development of system requirements is based on stakeholders' needs while still being achievable, verifiable, and unambiguous," as students' agreement strengthened, and confidence levels increased, across the two time points.

Item 3, "Requirements should specify subsystem elements and components," elicited valuable information from the students. Namely, while the students became more confident in their response post-survey (64.3% indicated they were very confident of their answer post-survey in comparison to the 52.9% of students who reported being very confident of their answer pre-survey), only two additional students post-survey answered item 3 correctly. Similarity, for item 4, "A system specification should contain the requirements for each element of the system," 57.1% of students denoted they were very confident post-survey, a gain of 10 percentage points from the pre-survey level; however, the number of students who correctly answered item 4 remained unchanged across time points. Given these results, and the fact that roughly a third of the students were only somewhat confident of their answers to these two items at each time point, there is indication more explicit attention should be paid to these topic areas in the next offering of the systems engineering interdisciplinary design course.

There was an increase in the number of student respondents who strongly agreed across time points (pre-survey ≈ 29%; post-survey ≈ 57%) for item 5 as students shifted their response from agreed to strongly agree in response to "Characteristics of a system can arise that cannot be found as a characteristic of any of its component parts." The students' confidence in their response for item 5 also grew post-survey as nearly 79% were very confident, an increase of 44 percentage points in comparison to the pre-survey level.

Nearly 93% of the students who responded post-survey indicated that they strongly agreed that "being able to describe, identify, create, and document an architecture of systems is fundamental to systems engineering" (item 6). This is in considerable distinction, and improvement, to the 41.2% of students who agreed and 52.9% who strongly agreed pre-survey. Furthermore, the students reported increased confidence post-survey with 100% of the student respondents very confident in their response. This is marked contrast to the approximately 65% of student respondents who reported being very confident, and the roughly 30% of student respondents who reported being somewhat confident, in the pre-survey.

A little over two thirds of students strongly disagreed and slightly more than one third disagreed, both pre- and post-survey, that “it is best to have everyone on the system design team have the same problem solving style” (item 7). These findings appear to indicate there was no change over the time points; however, the percentage of students who reported they were very confident in their response increased from roughly 65 percentage points pre-survey to nearly 93% post-survey, which suggests increased student certainty of their systems engineering knowledge.

The responses for item 8 “Schedules can be developed independently from the work-breakdown structure,” and item 9 “For most systems there are no distinctions between verification and validation,” provide evidence for the conclusion that student respondents’ systems engineering comprehension increased over the semester. The majority (41.2%) of the students who responded to Item 8 indicated agree pre-survey and half responded disagree post-survey. At the same time, they became more confident in their responses by the conclusion of the course as there was an increase of roughly 32 percentage points in the number of students who specified they were very confident in their response. Similarly, nearly half of the students who responded to item 9 selected not sure pre-survey and half indicated strongly disagree post-survey. Roughly 79% designated they were very confident in their response at the end of the semester, an increase from just over 47 percentage points pre-survey. The student responses for item 10 are unexpected as students’ confidences appeared to increase substantially across time points (very confident: 29.4% pre-survey; 85.7% post-survey), but the agreement ranking was split (disagree: 41.2% pre-survey; strongly disagree and agree: 35.7% post-survey) indicating possible confusion perhaps due to the wording of the item or not sufficiently learning this concept.

There are limitations of this study that must be discussed. One limitation is clearly the modest number of students enrolled in the course, which is an inherent constraint of senior design courses. As previously mentioned, the sample size was not sufficient to perform basic statistical comparisons, such as repeated measures *t*-tests. This hypothesis test restriction was due to power, which is the odds of indicating there is a relationship between the pre- and post-survey responses when there actually is a relationship. The minimum desirable level to place confidence in the conclusions generated from the results of such a test is 80%, which indicates 20% of the time significance will not be found when in fact it exists. As there is an inverse relationship between power level and sample size, pre- post-survey statistical conclusions could have been made, but there would not be much confidence in those conclusions.

Conclusions

Based on the results and analysis, it is evident that the students acquired a systems engineering knowledge base, despite the limitations mentioned above. The item score results that do not support systems engineering knowledge gain could be a product of the students’ undergraduate status as several of the questions appeared to be too difficult or ambiguous for the students. Also, it should be noted that this was presumably the students' first formal encounter with systems engineering concepts as well as the first time The Pennsylvania State University held such a course for undergraduates. Overall, these findings provide evidence that the systems engineering interdisciplinary design course covered topic areas pertinent to systems engineering as the students' knowledge of systems engineering increased over the duration of the semester; however, there are key areas that could be improved, and built upon, during the next iteration of this course.

Another indicator of the students' increased systems engineering knowledge can be seen in the quality of the prototypes delivered at the end of semester. Fully-functional prototypes are a goal and expectation for all senior capstone projects at Penn State, but this result is not always achieved or solutions delivered lack functionality, reliability, or are simply poorly constructed. The four teams in this project all developed fully-functional, well-constructed prototypes at the end of the semester and two of the four teams were awarded prizes by independent judges at the college-wide Design Showcase. Although numerous factors contributed to this success, the systems engineering methodology focused students' attention to design detail across the four inter-related PEAK subsystems.

It is our opinion that exposing undergraduate students in the more traditional engineering fields to systems engineering fundamentals, and allowing them to apply those fundamentals in a course such as the SE Capstone, is an effective method to provide exposure to and an appreciation of systems engineering principles. However, in order for "systems thinking and systems engineering to permeate both undergraduate and graduate programs" as INCOSE's vision for systems engineering in 2020[3] states, this exposure will need to occur earlier in the curriculum and in more depth.

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[4] Defense Logistics Agency, Pre-positioned Expeditionary Assistance Kits (PEAK), 2010, Solicitation Number SP4705-10-R-PEAK.
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Appendix A Descriptive statistics from the pre- post-survey – general systems engineering knowledge questions

Item Pre-survey *N* = 17 Post-survey *N* = 14	**Time Point**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
1. The application of systems engineering process models is a fundamental aspect of systems engineering.	Pre-Agreement	4.35	0.786	2	5
	Post-Agreement	**4.64**	0.633	3	5
	Pre-Confidence	3.41	0.507	3	4
	Post-Confidence	**4.00**	.000	4	4
2. The development of system requirements is based on stakeholders' needs while still being achievable, verifiable, and unambiguous.	Pre-Agreement	4.24	0.831	2	5
	Post-Agreement	**4.79**	0.426	4	5
	Pre-Confidence	3.12	0.993	1	4
	Post-Confidence	**4.00**	0.000	4	4
3. Requirements should specify subsystem elements and components.*	Pre-Agreement	**4.00**	1.173	1	5
	Post-Agreement	3.64	1.499	1	5
	Pre-Confidence	3.35	0.862	1	4
	Post-Confidence	**3.64**	0.497	3	4
4. A system specification should contain the requirements for each element of the system.*	Pre-Agreement	3.88	1.166	2	5
	Post-Agreement	**4.00**	1.414	1	5
	Pre-Confidence	3.24	0.903	1	4
	Post-Confidence	**3.50**	0.650	2	4
5. Characteristics of a system can arise that cannot be found as a characteristic of any of its component parts.	Pre-Agreement	4.18	0.636	3	5
	Post-Agreement	**4.21**	1.251	1	5
	Pre-Confidence	3.06	0.966	1	4
	Post-Confidence	**3.79**	0.426	3	4
6. Being able to describe, identify, create, and document an architecture of systems is fundamental to systems engineering.	Pre-Agreement	4.47	0.624	3	5
	Post-Agreement	**4.93**	0.267	4	5
	Pre-Confidence	3.53	0.800	1	4
	Post-Confidence	**4.00**	0.000	4	4
7. It is best to have everyone on the system design team have the same problem solving style.*	Pre-Agreement	1.35	0.493	1	2
	Post-Agreement	**1.36**	0.497	1	2
	Pre-Confidence	3.65	0.493	3	4
	Post-Confidence	**3.93**	0.267	3	4
8. Schedules can be developed independently from the work-breakdown structure.*	Pre-Agreement	**3.18**	1.131	1	5
	Post-Agreement	2.29	1.069	1	4
	Pre-Confidence	2.47	1.281	1	4
	Post-Confidence	**3.43**	0.852	1	4
9. For most systems there are no distinctions between verification and validation.*	Pre-Agreement	**2.18**	0.883	1	3
	Post-Agreement	1.64	0.842	1	4
	Pre-Confidence	2.82	1.334	1	4
	Post-Confidence	**3.79**	0.426	3	4
10. Risks in system design generally can be identified, but are not quantifiable.*	Pre-Agreement	2.59	1.004	1	4
	Post-Agreement	**2.86**	1.610	1	5
	Pre-Confidence	2.94	0.966	1	4
	Post-Confidence	**3.86**	0.363	3	4

Note. * indicates reverse coded item.

Appendix B

Frequency statistics from the pre- post-survey – general systems engineering knowledge questions

Item	**Time Point**	**Level of *agreement***					**How *confident* are you in your response?**			
Pre-survey $N = 17$ Post-survey $N = 14$		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree	Just a Guess	Not Very	Somewhat	Very
1. The application of systems engineering process models is a fundamental aspect of systems engineering.	Pre *N* Pre %	0 0.0%	1 5.9%	0 0.0%	8 **47.1%**	8 **47.1%**	0 0.0%	0 0.0%	10 **58.8%**	7 41.2%
	Post *N* Post %	0 0.0%	0 0.0%	1 7.1%	3 21.4%	10 **71.4%**	0 0.0%	0 0.0%	0 0.0%	14 **100.0%**
2. The development of system requirements is based on stakeholders' needs while still being achievable, verifiable, and unambiguous.	Pre *N* Pre %	0 0.0%	1 5.9%	1 5.9%	8 **47.1%**	7 41.2%	2 11.8%	1 5.9%	7 **41.2%**	7 **41.2%**
	Post *N* Post %	0 0.0%	0 0.0%	0 0.0%	3 21.4%	11 **78.6%**	0 0.0%	0 0.0%	0 0.0%	14 **100.0%**
3. Requirements should specify subsystem elements and components.*	Pre *N* Pre %	1 5.9%	1 5.9%	2 11.8%	6 35.3%	7 **41.2%**	1 5.9%	1 5.9%	6 35.3%	9 **52.9%**
	Post *N* Post %	2 14.3%	2 14.3%	0 0.0%	5 **35.7%**	5 **35.7%**	0 0.0%	0 0.0%	5 35.7%	9 **64.3%**
4. A system specification should contain the requirements for each element of the system.*	Pre *N* Pre %	0 0.0%	3 17.6%	3 17.6%	4 23.5%	7 **41.2%**	1 5.9%	2 11.8%	6 35.3%	8 **47.1%**
	Post *N* Post %	1 7.1%	2 14.3%	1 7.1%	2 14.3%	8 **57.1%**	0 0.0%	1 7.1%	5 35.7%	8 **57.1%**
5. Characteristics of a system can arise that cannot be found as a characteristic of any of its component parts.	Pre *N* Pre %	0 0.0%	0 0.0%	2 11.8%	10 **58.8%**	5 29.4%	2 11.8%	1 5.9%	8 **47.1%**	6 35.3%
	Post *N* Post %	1 7.1%	1 7.1%	0 0.0%	4 28.6%	8 **57.1%**	0 0.0%	0 0.0%	3 21.4%	11 **78.6%**
6. Being able to describe, identify, create, and document an architecture	Pre *N* Pre %	0 0.0%	0 0.0%	1 5.9%	7 41.2%	9 **52.9%**	1 5.9%	0 0.0%	5 29.4%	11 **64.7%**
	Post *N*	0	0	0	1	13	0	0	0	14

of systems is fundamental to systems engineering.	Post %	0.0%	0.0%	0.0%	7.1%	**92.9%**	0.0%	0.0%	0.0%	100.0%
7. It is best to have everyone on the system design team have the same problem solving style.*	Pre *N*	11	6	0	0	0	0	0	6	11
	Pre %	**64.7%**	35.3%	0.0%	0.0%	0.0%	0.0%	0.0%	35.3%	**64.7%**
	Post *N*	9	5	0	0	0	0	0	1	13
	Post %	**64.3%**	35.7%	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	**92.9%**
8. Schedules can be developed independently from the work-breakdown structure.*	Pre *N*	2	2	5	7	1	6	2	4	5
	Pre %	11.8%	11.8%	29.4%	**41.2%**	5.9%	**35.3%**	11.8%	23.5%	29.4%
	Post *N*	3	7	1	3	0	1	0	5	8
	Post %	21.4%	**50.0%**	7.1%	21.4%	0.0%	7.1%	0.0%	35.7%	**57.1%**
9. For most systems there are no distinctions between verification and validation.*	Pre *N*	5	4	8	0	0	5	1	3	8
	Pre %	29.4%	23.5%	**47.1%**	0.0%	0.0%	29.4%	5.9%	17.6%	**47.1%**
	Post *N*	7	6	0	1	0	0	0	3	11
	Post %	**50.0%**	42.9%	0.0%	7.1%	0.0%	0.0%	0.0%	21.4%	**78.6%**
10. Risks in system design generally can be identified, but are not quantifiable.*	Pre *N*	2	7	4	4	0	2	2	8	5
	Pre %	11.8%	**41.2%**	23.5%	23.5%	0.0%	11.8%	11.8%	**47.1%**	29.4%
	Post *N*	5	1	1	5	2	0	0	2	12
	Post %	**35.7%**	7.1%	7.1%	**35.7%**	14.3%	0.0%	0.0%	14.3%	**85.7%**

Note. * indicates reverse coded item.