The Impact of a Systems Engineering Course on Capstone Project Performance

Robert Choate and Stacy S. Wilson
Western Kentucky University

Abstract

The Department of Engineering at Western Kentucky University has created a new Systems Engineering Minor to enhance the educational opportunities of students. A foundational component of the minor is a course, Principles of Systems Engineering, which is required for all students enrolled in the minor. The topics of project life cycle, scope and concept of operations, system architecture, analytical hierarchy, robust design, and design fundamentals are included in this course. The Principles of Systems Engineering course has been offered in several different semesters to upper division civil, electrical and mechanical engineering students. A set of assessment tools has been created to measure student learning and the impact of the Principles of Systems Engineering course on the capstone projects.

Keywords

Systems Engineering, Assessment, Capstone Project

Introduction

Several significant trends in the global environment are leading to the emergence of a more widespread and effective application of the systems engineering practice. There is a growing realization that systems engineering is essential to successfully design, develop and sustain the highly complex systems of the 21st century. Therefore, an increasing number of universities are offering programs in systems engineering, while simultaneously a number of corporations in the commercial and defense sectors have articulated needs for systems engineering skills and competencies. The demand in these sectors is strong for trained, experienced systems engineers, especially those who can think holistically about complex problems, are comfortable with the increasing complexity of systems that address those problems, can manage the uncertainty and complexity of the environment in which those systems are being built, and can respond to demands to shorten the time to deliver systems to the field.

This paper will discuss a new minor offered at WKU in the Department of Engineering, particularly a Principles of Systems Engineering course. Also, assessment of the minor relating to student performance in the senior capstone experience will be presented.

Systems Engineering Minor

In order to increase student awareness of the importance of system engineering, faculty in the WKU Department of Engineering developed a minor in systems engineering. The minor provides a pathway for students through an extension of regular engineering courses. This is consistent with the industry attitude that engineering students need a foundational background

in one of the traditional engineering disciplines, plus practical, real-world experience to become effective as systems engineers. Unlike systems-centric programs, which treat systems engineering as a separate discipline were most of the courses are taught focusing on systems engineering principles and practice, our domain-centric program offers systems engineering as an option that can be exercised within another major field in engineering. Therefore, the objectives for the graduate in engineering with a systems engineering minor are to:

- Attain programmatic or technical leadership roles in an organization identifying, formulating, designing and/or testing practical solutions to engineering problems and guide the engineering development of modern complex and interdisciplinary systems; while
- Employing systems engineering methods and tools in the development of advanced complex and interdisciplinary systems.

The Systems Engineering Minor requires a minimum of 21 credit hours. Students must complete a minimum of nine credit hours chosen from electives and the following required courses:

- Circuits and Networks or Engineering Statics
- Applied Statistics
- Principles of Systems Engineering

The Principles of Systems Engineering course is a new course that has been created as the foundational course for the minor. The details regarding this course will be presented below.

Principles of Systems Engineering Course

Systems engineering is an iterative approach to problem solving that examines all stages of a system's life cycle: design/development, production/construction, operation/maintenance, and retirement/disposal. Systems engineers develop high-quality, cost-effective solutions that meet the needs of their customers. NASA has identified systems engineering as "a critical core competency in enabling current and future mission success".[1]

Data available from INCOSE (International Council on Systems Engineering) indicates growth in systems engineering programs, with the number of masters programs in systems engineering growing faster in comparison to the number of undergraduate and doctoral programs. For example, within the USA there are currently 13 Bachelor of Science, 41 Master of Science, and 14 PhD programs that include the words "systems engineering" in their title.[2] However, an infusion of systems thinking and limited exposure to systems engineering principles is beginning to appear in many undergraduate engineering curricula. Within the WKU engineering programs, the use of scenario- or project-based education and team projects has been its cornerstone since inception. These experiences provide the opportunity for students to apply "systems engineering" to real-world problems.

The importance of understanding systems engineering principles and practices is becoming widely known in the engineering community. This course is the foundation course for the systems engineering minor. The objective of this course provides the student with an

introduction to systems engineering principles. The course is also intended to prepare the student for their capstone design course. Additional learning objectives include:

- to develop a systems engineering perspective of how complex systems are conceived;
- to establish and increase the knowledge and comprehension of the value and purpose of systems engineering;
- to establish a working knowledge of methods and tools systems engineers use; and
- to understand the roles of systems engineers and gain the ability to contribute to the development of complex systems.

The content outline for this course includes the following topics: the systems engineering process, requirements, design fundamentals, subsystem fundamentals, trade studies, integration, technical reviews, and case studies and ethics.

Principles of Systems Engineering Course Assessment

Two assessment instruments were developed for the foundation course. The Pre-Assessment will be administered at the beginning of the ENGR 400 (Principles of Systems Engineering) course to assess student understanding of system engineering. The Post-Assessment will be administered near the end of the ENGR 400 course to understand the impact of the minor on student learning and project skills particularly relating to the senior/capstone project experience. The engineering students at Western Kentucky University are required to complete a senior capstone project course sequence.[3, 4, 5] The first course in the sequence typically includes minimal instruction on project management and planning. The students begin executing the project plan during the first semester and then complete the project work and documentation during the second course in the sequence.

An assessment instrument was created to measure the understanding of systems engineering topics that students have prior to taking the course. Students were asked to consider a project that they have complete and rate their understanding of the following topics:

- Project Life Cycle (Waterfall Process Model, Spiral Process Model, "Vee" Process Model);
- Requirements;
- Scope and Concept of Operations;
- System Architecture;
- Analytic Hierarchy Process;
- Functional Analysis (IDEF model, Functional Flow Block Diagram, Time Line Analysis)
- System Synthesis and Robust Design (Taguchi Method);
- Design Fundamentals;
- Economic Evaluation;
- Interfaces (N^2 Interface);
- Risk Management (Risk Matrix, Fault Tree, Failure Mode Analysis); and
- Validation and Verification (Inspection, Analysis, Demonstration, Test).

Students are also asked to respond to one of the three statements below:

- I have no knowledge of systems engineering and do not know what topics to expect in ENGR 400.
- I have some knowledge of systems engineering and have a low level understanding about this course.
- I am very familiar with systems engineering and have used it in the past.

Another assessment instrument was created to measure student learning.. Students were asked to rate their understanding of the previous list of topics.

Students are also asked to respond to the one of the statements below:

- Our team did not use system engineering techniques learned in ENGR 400 during our senior/capstone project.
- Our team *rarely* used system engineering techniques learned in ENGR 400 during our senior/capstone project.
- Our team has used *some* system engineering techniques learned in ENGR 400 during our senior/capstone project.
- Our team has used *many* system engineering techniques learned in ENGR 400 during our senior/capstone project.
- Our team has used *most of the* system engineering techniques learned in ENGR 400 during our senior/capstone project.

Results

Two cohorts of students have completed the pre-assessment instrument. Eighteen and nine students completed the assessment during the spring 2014 and fall 2014 semesters, respectively. In the first cohort, the students were all EE and ME majors while the Fall 2014 semester class is a mixture of CE, EE, and ME majors with the demographics shown in the table below:

Table 1: ENGR 400 Pre-Assessment Student Demographics

	Spring 2014	Fall 2014
Completed Senior/Capstone Project	0/18	2/9
Enrolled in Senior/Capstone Project	8/18	5/9
Have not taken Senior/Capstone Project	10/18	2/9

When asked to report the familiarly with the topic of systems engineering, the results are shown in the table below.

Table 2: Student Familiarity with Systems Engineering

Statement	Spring 2014	Fall 2014
I have no knowledge of systems engineering and do not know what topics to expect in ENGR 400.	16%	33%
I have some knowledge of systems engineering and have a low level understanding about this course.	84%	67%
I have some knowledge of systems engineering and have a low level understanding about this course.	0%	0%

Students were asked to rate their understanding of the topics in the course outline prior to the beginning of the course according to the following metric:

1= I don't know anything about this topic.
2= I have been introduced to this topic but didn't use it in my project.
3=I have some understanding of this topic but didn't find it relevant to my project.
4= I understand this topic and used it in my project.
5= I completely understand this topic and used it extensively in my project.

Figure 1 below summarizes the average student responses per semester. Notice that no average response exceeded 4 which would indicate that students were not familiar with the course outline topics prior to the course.

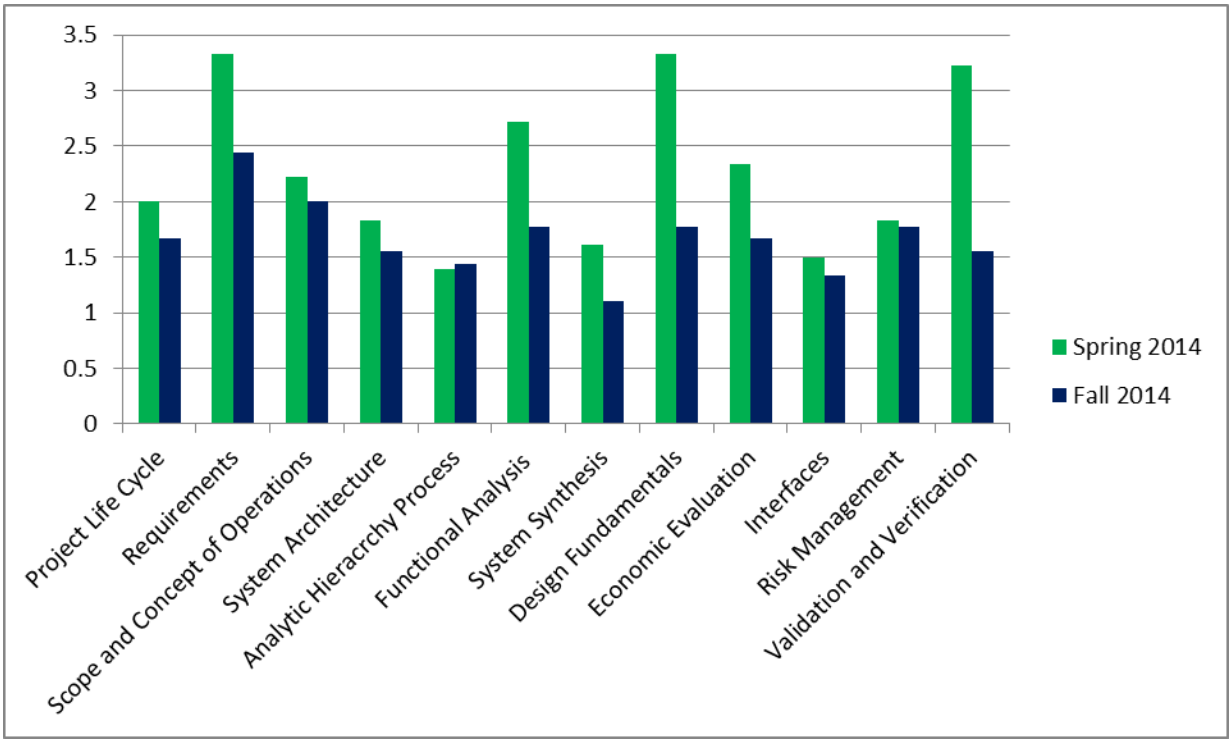

Figure 1: Pre-Assessment Topical Understanding Response

Two student cohorts also completed post assessment of the systems engineering course. Nine and seventeen students completed the assessment during the Summer 2013 and Spring 2014 semesters, respectively. These classes were composed of all EE and ME majors.

Table 3: ENGR 400 Post-Assessment Student Demographics

	Summer 2013	Spring 2014
Completed Senior/Capstone Project	0/9	0/18
Enrolled in Senior/Capstone Project	0/9	8/18
Have not taken Senior/Capstone Project	9/9	10/18

Students were also asked to respond to the degree to which system engineering techniques learned in the introduction to systems engineering course were used in their senior/capstone design projects. The table below summarizes the results for both semesters.

Table 4: Use of Systems Engineering Techniques in Capstone Project

	Summer 2013	Spring 2014
Our team did not use system engineering techniques learned in ENGR 400 during our senior/capstone project.	0%	0%
Our team *rarely* used system engineering techniques learned in ENGR 400 during our senior/capstone project.	0%	0%
Our team has used *some* system engineering techniques learned in ENGR 400 during our senior/capstone project.	33.3%	52.9%
Our team has used *many* system engineering techniques learned in ENGR 400 during our senior/capstone project.	44.4%	41.2%
Our team has used *most of the* system engineering techniques learned in ENGR 400 during our senior/capstone project.	22.2%	5.9%

Students were asked to rate their understanding of the topics in the course outline at the end of the course according to the same metric used previously:

1= I don't know anything about this topic.
2= I have been introduced to this topic but didn't use it in my project.
3=I have some understanding of this topic but didn't find it relevant to my project.
4= I understand this topic and used it in my project.
5= I completely understand this topic and used it extensively in my project.

The figure below summarizes the average student responses per semester. As seen in the figure, the student understanding of system engineering topics greatly improved in the post-assessment as expected.

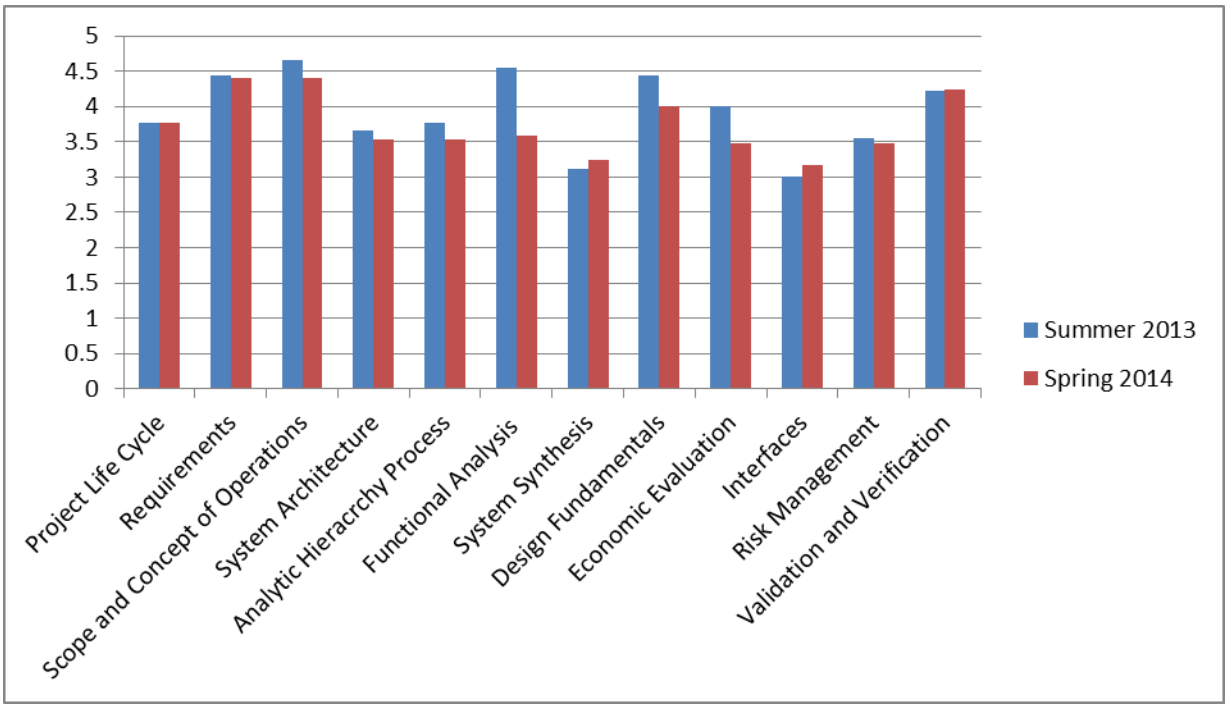

Figure 2: Post-Assessment Topical Understanding Response

The Spring 2014 students completed both the pre and post assessment. The results of their assessment are shown in the figure below. By comparing the pre- and post-assessment of the same cohort of students, the increase in student understanding of system engineering topics is further validated.

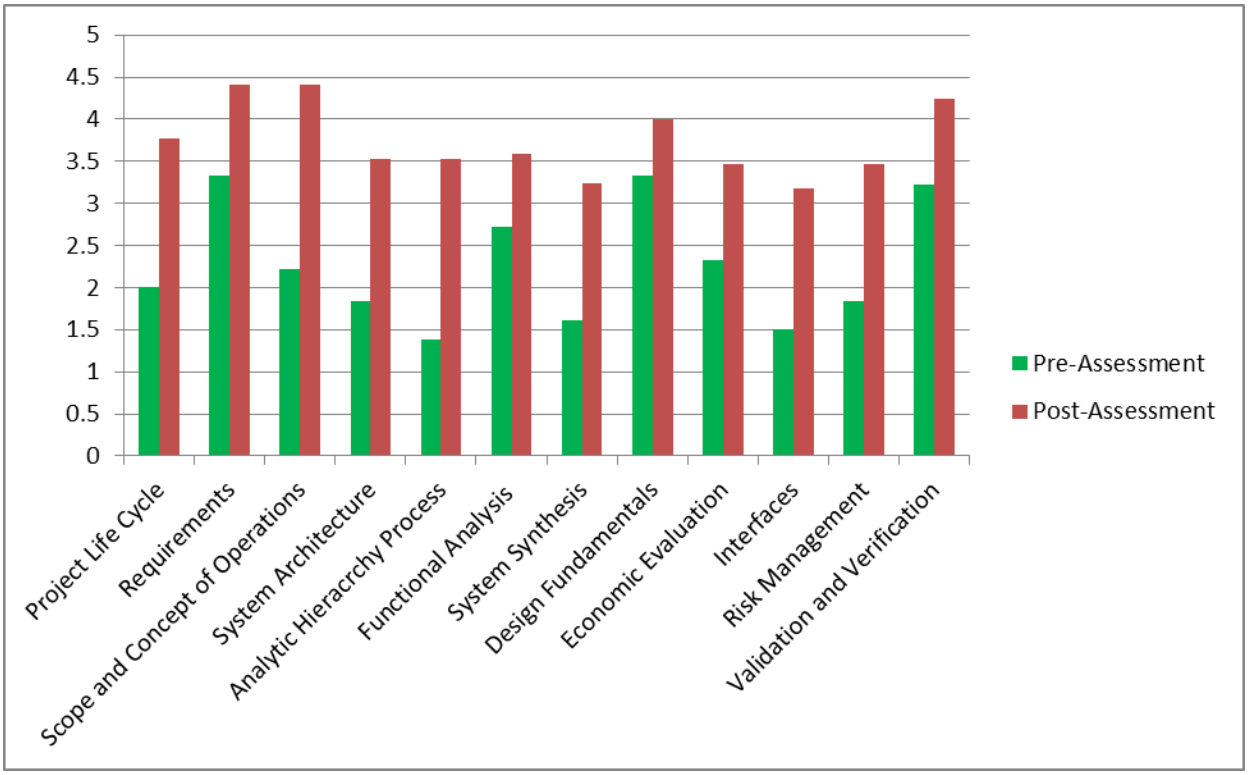

Figure 3: Comparison of Pre- and Post-Assessment Results for Spring 2014 Cohort

The students were asked to comment on how this Principles of Engineering course helped them complete their capstone project. Many students indicated that it would have been valuable to have this course prior to enrolling or completing their capstone design.

Conclusion

The field of Systems Engineering is emerging as a connection between many of the traditional engineering fields. The minor in systems engineering offers students the opportunity to expand their understanding of systems and how the effective management of systems influences virtually every aspect of our global societal challenges. Students who complete this minor will be better prepared to successfully solve many of these modern engineering challenges.

The Principles of Systems Engineering Course provided students with a strong foundation in understanding systems engineering topics. Through assessment, it was shown that student understanding of fundamental systems engineering topics increased as a result of the course. Also students expressed that this course would be a valuable pre-requisite to their capstone design courses.

In the future, the students taking the Principles of Systems Engineering will continue to complete pre- and post-assessments. The feasibility of including this course as a pre-requisite to capstone design will be studied.

References

1 "Systems Engineering," last modified February 24, 2015, http:// http://www.nasa.gov/directorates/heo/scan/engineering/overview/txt_accordion3.html.

2 "Directory of Systems Engineering Academic Programs," last modified on February 24, 2015, http://www.incose.org/educationcareers/academicprogramdirectory.aspx.

3 Schmaltz and Choate, "Improving Student Design Skills through Successive Design and Build Projects," 2006 ASME IMECE Conference Proceedings, Chicago, IL, November 2006.

4 Schmaltz, Byrne, Choate, and Lenoir, "Integrated Professional Component Plan from Freshmen Experience to Senior Project," 2004 ASEE Annual Conference Proceedings, Salt Lake City, UT, June 2004.

5 Wilson, Stacy, and Mark Cambron, Michael McIntyre. "Assessing and Improving a Capstone Design Sequence with Industrial Project Management Techniques," 2011 ASEE Annual Conference Proceedings, Vancover, Canada June 2011.

Robert Choate

Robert Choate is a Professor of Mechanical Engineering at Western Kentucky University. He teaches thermo-fluid and professional component courses, including Thermodynamics, Fluid Mechanics, Systems and Reliability Engineering, Thermo-Fluid Systems Lab and ME Senior Project Design course sequence. Prior to his appointment at WKU, he was a principal engineer for CMAC Design Corporation, designing thermal management solutions for telecommunication, data communication and information technology equipment.

Stacy S. Wilson

Stacy S. Wilson is the director of the Western Kentucky University Engineering-Manufacturing-Commercialization Center (EMCC) and is a professor in the WKU Electrical Engineering Program. She is a licensed engineer in the Commonwealth of Kentucky. Dr. Wilson's expertise is in control systems, system identification, microprocessors, and systems engineering. Her current research interests include cyber physical systems, system identification, and applied controls topics.