Assessment of Student Outcomes in a Distinctive Engineering Program

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Assessment of Student Outcomes in a Distinctive Engineering Program: the Role of Senior Capstone Design

University of Arkansas, Little Rock (UALR) undergraduate systems engineering program recently hosted an ABET accreditation visit. As per current ABET policy, the program was evaluated on ABET general criteria alone. The systems engineering program is distinctive in nature in that it introduces core systems engineering concepts at undergraduate level. The program offers concentrations in electrical systems, computers systems, and mechanical systems engineering. In this paper we discuss the role of multi-disciplinary senior capstone design in the assessment of student outcomes in the systems engineering program.

Background

The UALR undergraduate systems engineering program was put in place in 1999 to support the high-technology industry needs in the central Arkansas region. The program started with two options, i.e., telecommunications and computer systems options. The first batch graduated from the program in 2004. The program was visited by ABET in 2005 and accredited in the following year in 2006. The year 2005 also saw the launch of two new options, i.e., Electrical and Mechanical Systems options. Telecommunications option was suspended in 2013 due to low enrolment; thus, currently the program offers concentration options in Electrical, Mechanical, and Computer systems.

The program curriculum includes the following components: a) a university core of 21 hours that includes humanities and social sciences; b) a 14 hour college core that includes additional math and science; c) a 32 hour systems engineering core that includes courses in computer programming, circuits, probability and random signals, engineering economy, optimization methods, decision and risk analysis, DES simulation, systems engineering design and analysis and a two-part Senior Capstone design; and, d) a 32 hours option core that includes discipline specific courses in Electrical, Mechanical, or Computer Systems. Upon graduation, most of our students find jobs in local industry in one of the three option areas, working in local industries such as Southwest Power Pool, Caterpillar, Molex, Dillards, Cameron, AT&T and others in Arkansas and beyond. Some students enroll in the graduate programs and continue on to obtain Master's degree in engineering or business.

The program is unique and distinctive in many ways. UALR is one among very few institutions that offer Systems Engineering specialization at an undergraduate level. The program curriculum includes four systems engineering core subjects: Optimization Methods in Systems Engineering, DES Simulation, Decision and Risk Analysis, and Systems Engineering Design and Analysis. Additional systems related core courses include Engineering Economy, and Probability and Random Signals. Additionally, several discipline related courses emphasize systems concepts, and include Circuits and Systems, Signals and Systems, Digital Systems, Control Systems, Microprocessor Systems, Power Systems, and Digital and Analog Communications Systems. Systems engineering students also take an upper level business elective. The Capstone Designs projects are multi-disciplinary and mostly cover systems level design. Please see Appendix B for examples of recent Capstone Design projects.

Systems engineering program assessment includes assessment of student outcomes that mirror the ABET a-k outcomes. These outcomes are assessed in the system engineering core courses (see Appendix: Table 1). The achievement of each of the 11 SYEN student outcomes (SOs) is to be demonstrated by a primary core course and often by one supporting course. The assessment of each SO is based on quantitative performance measures that directly assess the SO. Assessment methodology is based on the student work, such as assignments, exams, projects, presentations, laboratory experiments, etc. Samples of student work supporting assessment of SOs are retained and placed in the course binders maintained in the department office.

The student outcomes are assessed as per the assessment plan adopted by the department based on the following principles:

1. The achievement of each SO is to be demonstrated by a primary course and possibly by a supporting course. Both courses must be from the systems engineering core component that is completed by all students.
2. The achievement of each SOs should include the assessment of all components of that particular SO.
3. The methodology of measurement should be straightforward, measuring directly the achievement of the SO by measuring the achievement of its component parts instead of by indirect means such as measuring the accomplishment of course learning objectives and then mapping the objectives to the SO.
4. Assessment methodology may be based on samples of the student work such as assignments, exams, projects, presentations, laboratory experiments, etc.

Course instructors for designated courses complete and submit a standardized assessment Performa at the end of each semester. These are then reviewed and scrutinized by the departmental assessment committee. Any recommendations from the assessment committee are discussed in the departmental faculty meeting, and appropriate actions initiated. Additionally, samples of student work supporting assessment are retained and placed in the course binders maintained in the department office.

The expected level of attainment on student outcome assessment measures varies, depending on the assessment instrument (Table 1). On most tools that use numerical grades (e.g., test or homework scores), an average score of 70% or higher from all students taking the assessment is considered satisfactory. On assessments that are normally scaled or graded on a curve, a rating is determined only on those students who receive a grade of ‘C’ or better in the course. A rating of satisfactory requires the average student performance on the assessment instruments equal the average of those students who received a grade of ‘B’ in the course. On assessment instruments that do not use a numerical grade, a rating of satisfactory requires that 70% of students meet the minimal criteria for acceptable performance. A rating of marginal means though the criteria for an overall satisfactory rating on a student outcome were met, but were within 3% of being unsatisfactory.

Table 1: Assessment instruments used to assess student outcomes

Assessment Instrument	Student Outcomes Assessed										
	a	b	c	d	e	f	g	h	i	j	k
Homework Problems	x	x	x		x			x		x	x
Exams	x	x	x							x	x
Capstone Project Assessment			x	x							
Peer Evaluations				x							
Video and Exam						x					
Capstone Reports			x				x	x	x	x	
Class Oral Presentations							x				
Class Project		x		x	x		x				x

The Role of Senior Capstone Design

The capstone design course provides a natural opportunity for assessing student outcomes[1]. We use capstone design classes for a large portion of our assessment, including student outcomes c, d, g, h, i, j. Our design classes are different from most engineering programs in that are student teams have true multidisciplinary backgrounds. All our students have taken several systems engineering courses. In addition, each student will have a background in electrical engineering, computer engineering or mechanical engineering. Capstone projects are completed by teams of two to four students. All design teams will have skills in systems engineering and at least one other discipline.

Systems engineers deal with projects from a big picture perspective[2]. One of the jobs of a systems engineer is to come up with project specifications. To do this, the engineer often must translate perceived goals into concrete requirements that address a real problem, which may actually be different from the original problem description. Students must use a series of tools or methods to help them do that. One of them is an idea checkpoint, which students use to define goals for their projects. In the idea checkpoint report (see Appendix), students must come up with a project narrative that describes what they want to do, who will benefit from their project and why someone will want to use their invention or device.

The next step in the capstone design is to come up with a job statement[3]. This is a way to change the perspective of students, getting them to start thinking about the problem they are solving in a different way. A job statement looks at devices from the viewpoint of what job the user is trying to get accomplished with those items.

Once we know what the job is, we can ask who wants to get this job done. There may be multiple types of people who want to get a job done for different reasons. For example, teenagers may want to use a weightlifting machine to improve their looks, but an elderly person may use that same machine in order to maintain bone density. For each type of user we can ask, what are their expectations of that device? The next step is to ask how well is the current solution meeting user needs? This can sometimes be difficult to do, especially if a user is very different from the capstone students.

One method to help students accomplish this is a method borrowed from the Stanford Design Program[4] called a camera study. In this method, users are given a camera and asked to perform their task. Whenever anything catches their attention (both good and bad), they are asked to take a picture. At the end of the session, they are asked to put the pictures in order and explain why they took each one. The camera study can be used to identify pain points, places in the process of doing a job where user expectations are not satisfactorily met. It is these unmet user expectations that are used to create project goals, and then design devices that meet these goals. The idea checkpoint report (see Appendix) becomes part of the project report and is used as one tool to assess outcomes c and h.

Although engineering is often thought of as a logical field, research shows that engineering design is often an intuitive process[5]. An important aspect of design education is helping students develop intuition, which puts engineering problems in perspective. This is why we require students to look back at their experience at the end of Capstone Design and answer the question: What would you do differently if you were starting the project over today? The answers to this question are used to asses outcome i.

Engineering students must often work in teams when they get into industry. Outcome d asks programs to assess whether students can work in multidisciplinary teams. Because of the nature of our program, all Capstone teams are multidisciplinary. However, we are considering taking that a step further. By the time engineering students become seniors, they tend to approach problems in the same way. How can we get students to work effectively with students who use different cognitive styles to solve problems? The department created an experimental set of courses in Creative Design taken by students majoring in psychology, art or engineering. Teams formed based on results of Myers-Briggs personality type test, with each team having multiple personality types on each team. One purpose of the course is to foster smoothly running teams by developing trust between team members. One day, we would like to use this or similar courses to assess the true abilities of our students to work in diverse teams.

Assessment of Outcomes in Senior Capstone Design

As determined by the departmental assessment committee, the SOs to be assessed through SYEN 4385 and SYEN 4386 are as follows:

(c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
(d) An ability to function on multidisciplinary teams.
(f) An understanding of professional and ethical responsibility.
(g) An ability to communicate effectively.
(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
(i) A recognition of the need for, and an ability to engage in life-long learning.
(j) A knowledge of contemporary issues.

Capstone Design Projects Recently Undertaken

In 2015, there were 12 students enrolled in SYEN 4386 who were assigned to 6 project teams based on their areas of interest and backgrounds. The project titles, in random order, consisted of:

1. Myoelectric Hand
2. Universal Zero-Turn Mower Utility Attachment
3. Motorcycle Interactive Lighting System
4. Accident Detection and Notification System
5. 8” 600 Class 8800 General Valve Design
6. Solar Powered Cooling System

Assessment Instruments

The student performance in SYEN 4386 is assessed and the final grade is calculated based on the following:

> **Weekly progress reports**: The students submit their individual progress reports on a weekly basis. Based on these individual reports, the team leaders also provide a weekly progress report for the group. These reports are expected to follow the detailed project schedules which are prepared during the first semester. Feedback is provided to students based on their progress reports. For every three progress reports “not submitted” or graded as “unsatisfactory,” the final grade is reduced by one letter, i.e. from A to B, or B to C, etc. Late progress report is not accepted.
>
> **Midterm report:** This report is a compilation of the weekly reports. It is to be submitted by the project team using the “Final Report” format. Each team member prepares his/her section(s) and submits it to the project leader so that s/he can email it to the project advisor(s) by the specified deadline. Midterm report counts as three progress reports. Late midterm report is not accepted. 2
>
> **Final report:** The final report is to be submitted by the end of the semester before the project presentations. The final project report format requirements are same as the ones used in SYEN 4385, see appendix. Late final report is not accepted.
>
> **Final oral presentation:** Each team makes a 30-minute PowerPoint presentation of the project followed by a 10-15 minutes of “questions and answers” session. All System Engineering (SYEN) students and faculty, and the dean and his staff who contribute to the projects are invited to these presentations. The rubrics and weights used in project evaluation are as follows: Project evaluation rubric 65 points, i.e. 48% Final report evaluation rubric 45 points, i.e. 33% Final oral presentation rubric 25 points, i.e. 19% Total 135 points i.e. 100% The final grade of an individual on the project is adjusted using the “Peer Evaluation Rubric. All rubrics are given in the appendix. Regular attendance is taken. If a student misses four weekly meetings, his/her final grade is reduced by one letter, i.e. from A to B, or B to C, etc. Anybody who misses 5 classes or more receives a final grade of “F.”

Assessment of SO(c)

PO(c) includes "An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." The outcome of the Capstone II course (SYEN 4386) is a project which involves and addresses this PO, i.e. "Ability to design a system." In addition to the regular course work, supportive topics are introduced in Capstone I (SYEN 4385) to support the ability to design a system. These topics include review of production systems**,** design and decision making process, product and service design, engineering ethics, project management, economic analysis, process analysis and improvement, and design of production flow lines. These topics also support systems design under various conditions such as economic, ethical, manufacturability, etc.

Table 2: Results of assessment of SO(c)

Criteria	**Unsatisfactory**	**Marginal**	**Satisfactory**	**Excellent**	**Assessment Tool**	**Comments**
c - an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	0	1	2	3	Project Report	Successful (i.e., functional) project

The table shows that 5/6 or 83% performed satisfactorily or better, which is above the 70% threshold.

Assessment of SO(d)

SO(d) looks at how students work together in multidisciplinary teams. In Capstone I, students divide into teams of two – four members, depending on student interests and the difficulty of a proposed project. These teams remain together for Capstone I and II, completing an approved engineering project. The effectiveness of the teams is evaluated by two criteria. First, the finished project must be functional as defined by meeting the important "must have" goals of the project. If the team does not meet these goals, it is an indication that the team did not function effectively. Second, all students fill out a peer evaluation form that scores the performance of other team members. Low scores on the peer evaluation are used as an indicator of problems in team function. The assessment results are shown in Table 3. Table 3 indicates that 3/4 or 75 % of the teams performed satisfactorily or better on their ability to function on multidisciplinary teams.

Table 3: Results of assessment of SO(d)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
d - an ability to function on multidisciplinary teams	0	1	0	3	Functionality plus Peer Evaluations	Functionality required

Assessment of SO(f)

SO(f) includes "An understanding of professional and ethical responsibility." Students take a 2-hour ethics course entitled "Professional Ethics." The students in SYEN 4385 Capstone I also watched the DVD titled "Incident at Morales: An Engineering Ethics Story," produced and distributed by the National Institute for Engineering Ethics. A test was given on the video. Students were assessed on whether they could identify five or more ethical issues arising from the situation described in the video. The results are shown in Table 4. Twelve out of sixteen students (75%) in the course performed satisfactorily on the assignment.

Table 4: Results of assessment of SO(f)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
f - an understanding of professional and ethical responsibility	0	4	12	0	Ethics video homework	Identify 5 issues S

Assessment of SO(g)

SO(f) includes "An ability to communicate effectively." SYEN 4386 heavily depends on verbal and written communication skills. These skills are assessed through the final report and final oral presentation. All final reports were assessed as satisfactory or excellent. For the oral presentations, the results are given in Table 5. 6/6 or 100% of the teams performed satisfactorily or better on their oral presentation skills.

Table 5: Results of assessment of SO(g)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
g - an ability to communicate effectively	0	0	2	4	Presentation evaluation rubric	20+ E, 16-19 S, 11 - 15 M; <15 U

Assessment of SO(h)

SO(h) examines the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. For Capstone I, students are required to choose a problem and perform an assessment of existing solutions. They are also required to explicitly determine how their proposed solution is better than existing solutions. Twenty of twenty-two students (91%) were able to satisfactorily describe the impact of their engineering solutions, as shown in Table 6.

Table 6: Results of assessment of SO(h)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
h - the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	0	2	20	0	Idea evaluation report	

Assessment of SO(i)

SO(i) includes a recognition of the need for, and an ability to engage in life-long learning. In Capstone II, students must reflect upon the project they just completed and state what they would do differently if starting over again. Table 7 shows the results of this assessment. All six (100%) of groups performed satisfactorily or better on this factor.

Table 7: Results of assessment of SO(i)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
i - a recognition of the need for, and an ability to engage in life-long learning	0	0	5	1	Report	Reflection on project

Assessment of SO(j)

SO(j) looks at whether or not students have a knowledge of contemporary issues. Capstone II students must identify an engineering problem, look at competing solutions for the problem and propose a new solution that is superior in some way to existing solutions. Students are assessed on their knowledge of contemporary issues by whether or not they can identify the gaps in the existing solutions to the problem. Table 8 shows the results from the assessment. 5/6 or 83% of the groups performed satisfactorily of excellent on this factor.

Table 8: Results of assessment of SO(j)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
j - a knowledge of contemporary issues	1	0	3	2	Report	references, competing solutions

Assessment of SO(k)

SO(k) looks at whether or not students have an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. This was assessed by the Capstone II report, which covers the project analysis, design and construction tools used to build the group projects. As seen in Table 8, all 6 groups documented their use of modern engineering tools and techniques in their capstone projects.

Table 9: Results of assessment of SO(k)

Criteria	Unsatisfactory	Marginal	Satisfactory	Excellent	Assessment Tool	Comments
k - an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	0	0	5	1	Report	Design, analysis and construction tools

Conclusion

The UALR Systems Engineering program is a distinctive program in that it includes 15 hours of systems engineering tools and applications (normally taught at graduate level). Senior Capstone design plays a major part in the assessment of student outcomes in the systems engineering program. In this paper we have outlined the basic methodology used for assessment of SOs (c), (d), (f), (g), (h), (i), (j), and (k) in the Capstone Design Course. This methodology helped us toward a successful ABET accreditation visit in 2015.

Appendix

Table 1: Systems engineering student outcomes and their assessment

SO	Student outcome	Courses Used for Assessment
(a)	Ability to apply knowledge of math, science and engineering	SYEN 2315, 3310, 3312, 3314 or 3318
(b)	an ability to design and conduct experiments, as well as to analyze and interpret data	SYEN 3312, 3316, or 3318
(c)	an ability to design a system, component, or process to meet desired needs within realistic constraints	SYEN 4385/4386
(d)	an ability to function on multidisciplinary teams	SYEN 4385/4386
(e)	an ability to identify, formulate and solve engineering problems	SYEN 3312 or 3318
(f)	an understanding of professional and ethical responsibility	SYEN 4385/4386
(g)	an ability to communicate effectively	SYEN 4385/4386
(h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	SYEN 4385/4386 or 3318
(i)	a recognition of the need for, and an ability to engage in life-long learning	SYEN 3312 or 4385/4386
(j)	a knowledge of contemporary issues	SYEN 4385/4386 or 3318
(k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	SYEN 3312, 3316 or 4385/4386

Table 2: Systems engineering core courses used for assessment of student outcomes

SYEN 2315	Circuits and Systems
SYEN 3310	Dynamic Systems Modeling and Simulation
SYEN 3312	Optimization Methods in Systems Engineering
SYEN 3314	Probability Theory and Random Signals
SYEN 3316	Discrete Event Systems Modeling and Simulation
SYEN 3318	Decision and Risk Analysis
SYEN 4385/6	Systems Engineering Capstone Design I/II

Idea Checkpoint (Chapter 1 of final report)

1. Project Name

2. Date

3. Goals of the project

4. Narrative
    a. What do you want to do?
    b. Who will benefit?
    c. Why will they use your invention or device?

5. Job Statement
    a. What is the job to be done?
    b. What is your user trying to accomplish?
       Format: verb – object – context
       Example: eat – a healthy breakfast – on the go

6. Customer or user?
    a. Who will use your invention or device?

7. Unmet User Expectations
    a. List the expectations of your target user
    b. Which of these expectations is currently not being satisfactorily met?
       Format: direction – measurement – object of action – context
       Example: minimize – time needed to acquire – breakfast – in the busy morning

8. Competing Solutions
    a. What are the current options for getting the job identified in section 5 done?

Suggested Capstone Design Report Format

1. Project Name, participants and date

2. Narrative
    a. What did you plan to do?
    b. Who benefits
    c. What are the competing solutions?
    d. What other work is relevant (with references)?
    e. Why will people use your invention or device?
    f. Can you create a story or scenario clearly illustrates what your invention is, what it does and why people will want to use it over existing solutions?

3. Goals of the project

    a. What are the "must complete" goals for the project to be at all successful? In order to know these, you need to have a good understanding of who your end user will be, what job they are trying to get done and what are their unmet expectations. If there is more than one end user, write separate goals for each. Be specific, so you can easily tell if a goal was met or not.
    b. What are the goals that are highly desirable, but not essential?
    c. What are your "like to accomplish if we can" goals?

4. Functional block diagrams
    a. What is your design architecture
    b. What are the advantages of your chosen approach over the potential designs not used? What are its disadvantages? What are the tradeoffs of your design?

5. Detailed design
    a. Schematics, etc.
    b. What engineering standards are used in your design?

6. Budget

7. Gantt Chart or timeline showing milestones and completion dates. A milestone is a measurable accomplishment (e.g., fully functional prototype built and ready for testing)

8. Results
    a. Did you meet your goals?
    b. Include metrics, graphs, pictures, videos and demonstrations, as appropriate

9. If starting over again, what would you do differently?

References

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