

Capstone Design Outcome Assessment: Instruments for Quantitative Evaluation

David G. Meyer
Electrical & Computer Engineering
Purdue University
West Lafayette, Indiana

2005 Frontiers in Education Conference
Session F4D - Paper 1412

Outline

- Introduction
- Capstone Design Course Characteristics
- Capstone Design Outcome Assessment
- Purdue ECE Capstone Design Learning Outcomes
- Breakthroughs – Quantitative Evaluation Instruments
- Cohort Averages for Five Trials
- Outcome Remediation and Course Grade Determination
- Summary and Conclusions

Introduction

- Goal of work: develop and test quantitative instruments for assessment of capstone design course outcomes
- Underlying assumptions:
 - A proven method for satisfying ABET Criterion 3 is formulation of course specific outcomes that are mapped to the desired set of learning outcomes (a-k)
 - Quantitative assessment of course specific learning outcomes provides a better measure of student achievement than “student self-assessment, opinion surveys, and course grades”

Capstone Design Course Characteristics

- According to Criterion 4, a “...major design experience based on knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints”
- Properly implemented, a capstone design course could effectively be used to demonstrate student achievement of (many/most) Criterion 3 learning outcomes*

*Davis, K. C., “Assessment Opportunities in A Capstone Design Course,” 2004 American Society for Engineering Education Conference Proceedings

Criterion 3

peripheral
 direct

- a) an ability to apply knowledge of mathematics, science, and engineering
- b) an ability to design and conduct experiments, as well as to analyze and interpret data
- 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

Criterion 3

peripheral
 direct

- d) an ability to function on multi-disciplinary teams
- e) an ability to identify, formulate, and solve engineering problems
- 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

Criterion 3

■ peripheral
■ direct

- i) a recognition of the need for, and an ability to engage in, life-long learning
- j) a knowledge of contemporary issues
- k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Capstone Design Outcome Assessment

- Ways to measure how well engineering students can apply classroom knowledge and skills to realistic design problems*
 - authentic assessment
 - performance-based assessment

*Atman, C. J., et al., "Matching Assessment Methods to Outcomes: Definitions and Research Questions," 2000 American Society for Engineering Education Conference Proceedings

Capstone Design Outcome Assessment

- Authentic assessment – definition
 - key is to "create a context in which the student can individually or collaboratively demonstrate an ability to apply a well-developed problem-solving strategy"
 - involves "problem definition, gathering relevant information, generating solution alternatives, choosing the optimum solution given implicit and explicit constraints, assessing and improving the proposed solution, and effectively reporting results..."

Capstone Design Outcome Assessment

- Authentic assessment – issues
 - outstanding research issues include "development of well-designed scoring rubrics and methods for ensuring inter-rater reliability"
 - also needed are "guidelines... which help faculty choose tasks that are good candidates for collecting authentic assessment data in engineering courses"

Capstone Design Outcome Assessment

- National survey of design courses and assessment* – goals
 - obtain a better understanding of the nature and scope of assessment practices within capstone design courses across engineering disciplines
 - determine the extent to which current practices align with ABET EC 2000 expectations

*McKenzie, L. J., Trevisan, M. S., Davis, D. C., and Beyerlein, S. W., "Capstone Design Courses and Assessment: A National Study," 2004 American Society for Engineering Education Conference Proceedings

Capstone Design Outcome Assessment

- National survey of design courses and assessment – findings
 - uncertainty concerning sound assessment practices
 - uncertainty concerning appropriate assessment strategies
 - desire for more objective measures (more detailed scoring guidelines, grading rubrics)
 - desire for greater variety of assessment instruments

Purdue ECE Capstone Design Options Available

- i. EE Design Project (ECE 402)
- ii. **Digital Systems Design Project (ECE 477)**
- iii. Engineering Projects in Community Service (ECE 490)

"a structured approach to the development and integration of embedded microcontroller hardware and software that provides senior-level students with significant design experience applying microcontrollers to a wide range of embedded systems (e.g., instrumentation, process control, telecommunication, intelligent devices, etc.)"

Purdue ECE Capstone Design Learning Outcomes (Mapping)

1. an ability to apply knowledge obtained in earlier coursework and to obtain new knowledge necessary to design and test a system, component, or process to meet desired needs (a,b,c,e,i,j,k)
2. an understanding of the engineering design process (b,c,e,f,h)
3. an ability to function on a multidisciplinary team (d,h,j)

Purdue ECE Capstone Design Learning Outcomes (Mapping)

4. an awareness of professional and ethical responsibility (f,h,j)
5. an ability to communicate effectively, in both oral and written form (g)

Quantifying the assessment of these inherently qualitative course outcomes and determining appropriate thresholds to apply (gauging successful demonstration) has been a major challenge

Breakthrough – Outcomes 1 & 4

- Creating a series of **design component** and **professional component** "homeworks" (reports that serve as precursors of corresponding sections in the final written report)
- **Four** in each series – each team member completes **one from each series** (selection by mutual consent)
- Requires **team size of four**, and **course enrollment** that is an **integer multiple of four** (typical cohort size is 48/semester)

Design Component Homeworks (Outcome 1)

- Packaging Specifications and Design
- Schematic and Hardware Design Narrative/Theory of Operation
- Printed Circuit Board Layout
- Firmware Listing and Software Narrative

Professional Component Homeworks (Outcome 4)

- Design Constraint Analysis and Component Selection Rationale
- Patent Liability Analysis
- Reliability and Safety Analysis
- Social/Political/Environmental Product Lifecycle Impact Analysis

Sample Grading Rubric for Outcomes 1 & 4

Component/Criterion	Score (0-10)	Wgt	Pts
Introduction		X 1	
Results of Patent Search		X 3	
Analysis of Patent Liability		X 3	
Action Recommended		X 1	
List of References		X 1	
Technical Writing Style		X 1	

Threshold for successful demonstration is 60%

Breakthrough – Outcome 2

- Creating group accounts and team websites for hosting individual on-line lab notebooks
- Web-based approach allows students to include hyperlinks in their notebook entries to photos of prototyping setups, source code for testing various interfaces, video demos of project specific success criteria fulfillment, etc.
- Multiple evaluations (by different staff members) done – final evaluation determines whether outcome was successfully demonstrated

Grading Rubric for Outcome 2

Component/Criterion	Score (0-10)	Wgt	Pts
Technical content		X 3	
Update record/completeness		X 2	
Professionalism		X 3	
Clarity/organization		X 2	

Threshold for successful demonstration is 60%

Breakthrough – Outcome 3

- Defining a series of project success criteria
 - Five that are **common** to all projects:
 - Create a bill of materials and order/sample all parts needed for the design
 - Develop a complete, accurate, readable schematic of the design
 - Complete a layout and etch a printed circuit board
 - Populate and debug the design on a custom printed circuit board
 - Package the finished product and demonstrate its functionality
 - Five that are **specific** to the device implemented
- **Threshold for successful demonstration is 80%**

Breakthrough – Outcome 5

- Based on Design Review, Final presentation, and Final Written Report
- A minimum score of 60% on the **Design Review** and a minimum score of 60% on the **Final Report** and a minimum score of 60% on the **Final Presentation** is required to establish basic competency for this outcome

Summary

- Evaluation instruments chosen to quantitatively assess the five (Purdue ECE) capstone design learning outcomes include:
 1. a *design component homework* (to evaluate “an ability to apply knowledge...necessary to design and test a system, component, or process to meet desired needs”)
 2. the *individual lab notebook* (to evaluate “an understanding of the engineering design process”)
 3. the *project success criteria* (to evaluate “an ability to function on a multidisciplinary team”)

Summary

- Evaluation instruments chosen to quantitatively assess the five (Purdue ECE) capstone design learning outcomes include:
 - a professional component homework (to evaluate "an awareness of professional and ethical responsibility")
 - the *formal design review*, *final presentation*, and *final written report* (to evaluate "an ability to communicate effectively, in both oral and written form")

Cohort Averages for Five Trials

Outcome	Spr-03	Fall-03	Spr-04	Fall-04	Spr-05
1	85.5%	79.0%	81.7%	85.9%	80.8%
2	72.0%	81.3%	74.9%	84.7%	77.1%
3	93.3%	87.5%	85.0%	91.7%	91.4%
4	82.1%	81.5%	80.2%	84.6%	77.4%
5	85.7%	87.3%	85.9%	87.7%	85.3%

Typical cohort size is 48

Cohort Averages for Five Trials

Outcome	Spr-03	Fall-03	Spr-04	Fall-04	Spr-05
1	85.5%	79.0%	81.7%	85.9%	80.8%
2	72.0%	81.3%	74.9%	84.7%	77.1%
3	93.3%	87.5%	85.0%	91.7%	91.4%
4	82.1%	81.5%	80.2%	84.6%	77.4%
5	85.7%	87.3%	85.9%	87.7%	85.3%

Communication skills: most consistent evaluation instruments

Cohort Averages for Five Trials

Outcome	Spr-03	Fall-03	Spr-04	Fall-04	Spr-05
1	85.5%	79.0%	81.7%	85.9%	80.8%
2	72.0%	81.3%	74.9%	84.7%	77.1%
3	93.3%	87.5%	85.0%	91.7%	91.4%
4	82.1%	81.5%	80.2%	84.6%	77.4%
5	85.7%	87.3%	85.9%	87.7%	85.3%

Design and professional component homeworks: reasonably consistent evaluations for a given trial

Cohort Averages for Five Trials

Outcome	Spr-03	Fall-03	Spr-04	Fall-04	Spr-05
1	85.5%	79.0%	81.7%	85.9%	80.8%
2	72.0%	81.3%	74.9%	84.7%	77.1%
3	93.3%	87.5%	85.0%	91.7%	91.4%
4	82.1%	81.5%	80.2%	84.6%	77.4%
5	85.7%	87.3%	85.9%	87.7%	85.3%

Project success criteria: "natural variation" expected due to variety of projects attempted each semester

Cohort Averages for Five Trials

Outcome	Spr-03	Fall-03	Spr-04	Fall-04	Spr-05
1	85.5%	79.0%	81.7%	85.9%	80.8%
2	72.0%	81.3%	74.9%	84.7%	77.1%
3	93.3%	87.5%	85.0%	91.7%	91.4%
4	82.1%	81.5%	80.2%	84.6%	77.4%
5	85.7%	87.3%	85.9%	87.7%	85.3%

Lab notebooks: widely varying quality – attempting to improve by increasing the number of evaluations

Outcome Remediation

- Need to provide opportunities to correct deficient work (poorly written design/professional component paper, incorrect schematic, etc.)
- Complication: how to “count” updated score on corrected item toward course grade
- Another complication: proper handling of cases in which student otherwise passing (grade-wise) but deficient in one (or more) outcomes (e.g., due to hardware/software “bug”)

Course Grade Determination

TEAM COMPONENTS		INDIVIDUAL COMPONENTS	
Design Review	10%	Significance of Individual Contribution	10%
Final Video Presentation	10%	Lab Notebook Evals (2%, 3%, 5%)	10%
Final Report & Archive CD	10%	Design Component Homework	10%
Project Success Criteria	10%	Professional Component Homework	10%
Project Proposal	2%	PCB and Parts Acquisition	2%
User Manual	3%	Presentation Peer Review	4%
Senior Design Report	2%	Confidential Peer Reviews	2%
Poster	3%	Weekly Progress Briefings/Attendance	2%

50% based on team components, 50% based on individual components

Conclusions

- Many assessment strategies have been employed in capstone design courses, yet uncertainty persists concerning sound practices
- This paper has presented a systematic, quantitative strategy for assessing capstone design course outcomes and integrating the outcome assessment with course grade determination
- Data from five consecutive trials show that meaningful results can be obtained using this technique despite inter-rater differences

More Information

Detailed information about the course discussed in this presentation along with a copy of the presentation slides can be found at

<http://dynamo.ecn.purdue.edu/~meyer>