AC 2008-2059: USING WRITING TO ASSESS LEARNING IN ENGINEERING DESIGN: QUANTITATIVE APPROACHES

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INTRODUCTION

This poster (and paper supplement) presents the final results from NSF grant #0404923 – “Writing for Learning and Assessment in Engineering Design Courses.” Quantitative results are given from three years using Calibrated Peer Review™ (CPR™) as a pedagogy and assessment tool in a junior-level introduction to engineering design course.

We draw from a pilot project that used writing/communication assignments to improve the teaching of engineering design. We based our approach on the “writing across the curriculum” (WAC) movement’s premise that verbal composition is an analog for thinking and that communication artifacts can be used to infer student learning in complex problem-solving situations.

CPR™ -- as an advanced form of educational technology -- partners both with the student and with the instructor to monitor learning through formative assessment. In this project, through the vehicle of CPR™, we were able to implement assignments that fully utilize the WAC pedagogy, without overly increasing the workload for instructors. Furthermore, CPR™’s ability both to elicit and to report quantitative peer review helps to make formative assessment an integral part of instruction. And, the data collected by CPR™ during the student’s process of engaging the assignment gives faculty a deeper understanding of how students learn, resulting in better, more individualized feedback for students. CPR™’s extensive data summaries also allow for analysis of patterns and trends in aggregates of students, resulting in better faculty awareness in designing instruction for maximal benefit [1].

INTEGRATING CPR™ INTO AN ENGINEERING DESIGN CLASS

Most engineering programs have some type of capstone design experience in the senior year. At Rose-Hulman, the Electrical and Computer Engineering Department has taken this a step further by requiring a junior-level course (ECE 362: Principles of Engineering Design) which teaches the fundaments of design before the students start their capstone experience. The course is required for all electrical and computer engineering students. ECE 362 is – essentially – a technical writing course taught within the confines of a ten-week quarter.

Students explore, develop, and document the framework for a product idea they would like to pursue during their senior-level capstone course. The concepts of discipline-specific research, project design specifications, high-level design, detailed design, work breakdown schedules, budgets, and teaming skills are taught. All learning activities in the course culminate in a written proposal and an oral presentation requesting funds to develop the product.

In building the course around CPR over the last three years, we gained experience in authoring "writing as a way of learning" activities as well as insights into how best to link these units together. We now have nine assignments, all contributing toward the final course artifact, a professional-quality project proposal. The assignments and their sequence are detailed below in Table I.

TABLE I
NINE ASSIGNMENTS FOR ECE 362 – PRINCIPLES OF DESIGN

Assignment Title	Description
CPR 1: What Is Intellectual Property (IP)	Introduces IP in the form of patents, trademarks, industrial designs (trade secrets) and copyright law to the students. Patent protection is the major focus.
CPR 2: What Is An Annotated Bibliography	Introduces students to discipline research using the annotated bibliography. Students must find background materials on their product idea and then give descriptive and evaluative comments, assessing the nature and value of the cited works.
CPR 3: Market Analysis	Students are introduced to two methods of market analysis coupled with project idea generation: • **Augmented Projects** are existing products that are **added to or supplemented** to extend their functionality. These types of projects are the easiest to do since the base product is already developed. It is also relatively easy to get market information on these types of products. • **Bi-associated Projects** are projects that **combine two different products** and create a new product from the amalgam. These types of projects are more difficult to do since the combination of technologies or products may not be obvious. However, it is still relatively easy to obtain market information for each product and then estimate a market if the two different products were combined into one product.
CPR 4: Product Design Specification (PDS)	A Project Design Specification (PDS) should reflect the common knowledge of the team about the project. The students make use of their preliminary research to develop environmental, performance, and technology specifications for their projects.
CPR 5: Social Impact Statement	Requires students to reflect on their proposed project and write an impact assessment using the IEEE Code of Ethics [3] as the guidelines. For this assignment the students write one or two pages

	about the ramifications of their project on society.
CPR 6: Project Technical Description (PTD)	This document provides a concise explanation, which is not overly technical, while emphasizing the key components and incorporating appropriate visuals. The three essential elements of the project technical description are: 1. Description: starts with a very concise overview in order to put the features and benefits into context. 2. Visual Element: A picture, a sketch, screen shot, or a diagram that shows either the components of the product or how the product fits in its environment. 3. Key Benefits: Assesses the value of the product early in the statement. The use of bullet points is ideal. Then concludes by reiterating the advantages and relating them to a larger context. The students produce their first draft of the project technical description using the knowledge garnered during the previous CPR™ sessions.
CPR 7: Project Technical Description, Again	The students next take the feedback from CPR™s 1-6 and rewrite their project technical description emphasizing these specific elements: 1. Does the project technical description tell the reader what the product does in the opening paragraph or sentence? 2. Does the project technical description use concise and precise sentences along with concrete words to explain the product? 3. Does the project technical description use visual elements to help explain the product? 4. Does the project technical description present the key benefits of the product early in the presentation? 5. Does the project technical description present an analysis of any competitors? 6. Does the project technical description include an explanation of how the parts fit and function together? 7. Does the project technical description conclude with the key benefits of the product in paragraph form near the end of the description? 8. Does the project technical description convince the reader that this project can be done?
CPR 8: Product Design Specification, Again	The PDS will change substantially over the length of the project. Many factors cause a PDS to change, but the one element that has the greatest impact is the development of a deeper understanding of the product. As the student teams move forward developing

	their project proposal, they will always need to think more intensely about their project. The PDS should reflect the common knowledge of the team about the project. Therefore, the PDS needs to be regularly refined during the proposal phase to capture a deeper understanding of the team's process and product. At this point in the course, the PDS is revised and reviewed again using the following questions: 1. Is a function list given with a short description for each project-function? 2. Are performance specification given for each function? 3. Is the operating environment for the project given? 4. Are specifications relating to the operating environment provided? 5. Are target technologies identified to meet all of above?
CPR 9: Social Impact Statement, Again	Requires the students to re-examine their proposed project and rewrite their social impact statement using the IEEE Code of Ethics as a guideline, especially focusing on Item 1 of the Code: "To accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment." http://www.ieee.org/portal/pages/iportals/aboutus/ethics/code.html

Each CPR assignment requires students to evaluated three sample essays. Each student is then assigned a score based on their performance on these calibration essays. This score is reported as the Reviewer Competency Index – RCI. The "RCI" indicates how well the student "trained" during the calibration. RCI scores range from 1 (poor performance on the calibration essays) to 6 (excellent performance on the calibration essays). The algorithms embedded in CPR™ are beyond the scope of this paper. Suffice it to say that the calculations are very robust and that the instructor can set the level of tolerance for many of the indicators.

CLASSROOMS AS TESTBEDS FOR PEDAGOGICAL PARADIGMS:

While working with Calibrated Peer Review for the past three years, we were pleasantly surprised to find a pedagogical model serendipitously emerging from adaptations being made based on actual classroom experiences. We found that students profited by going through selected CPR modules for a second time, but at a higher level of expectation or with increased attention to the more nuanced facets of the exercise. This discovery based on best practice led us to the notion of the spiral curriculum, as advocated by Jerome Bruner [2].

Bruner's ideas have informed the teaching of composition for over two decades. The application of recursion to the teaching of writing and re-writing is almost intuitive. Curricula designed under this pedagogical model sequence activities so that learners return periodically to a previously covered topic to study the concept within the context of information they have learned in the meantime. Each return provides an opportunity to link new knowledge with existing knowledge. Bruner's theories have started to appear within the engineering education community as a framework for vertical integration of skills and competencies within degree programs [3].

We used the notion of recursion in assignments 7, 8, and 9 (see Table I), each of which asks the student to re-visit an engineering design task at a higher level of proficiency. Many features of Calibrated Peer Review™ lend themselves to recursion, as we discovered while creating a second, higher-order version for the Social Impact Statement, the Product Design Specification, and the Project Technical Description.

To test the efficacy of recursion, we looked at the CPR data for ECE 362, Spring Quarter. A total of 54 students participated in the PDS (Product Design Specification) exercises 1 and 2. We highlight the changes from version 1 to version 2 below.

- The rating rubric for PDS exercise 2 was increased in difficulty from PDS exercise 1;
- The text rating is based on calibration essays. The calibration essays all came from past projects that were successful and well written. Thus, the level of judgment need to apply the assessment rubric increased.
- The overall grade rubric was not changed from PDS exercises 1 to PDS exercises 2.

CPR™ lends itself to deep-structured sequencing of assignments, a method which should result in improved learning. Table II summarizes the results found by examining the data from Product Design Specification (PDS) 1 and 2.

Table II:
COMPARISON OF RESULTS FOR TWO VERSIONS OF PRODUCT DESIGN SPECIFICATIONS

PDS	PDS 1 Overall Grade	PDS 1 Text Rating	PDS 1 Reviewer Competency Index	PDS 2 Overall Grade	PDS 2 Text Rating	PDS 2 Reviewer Competency Index
Class Averages	91.91/100	7.78/10	5.02/6	93.02/100	8.13/10	4.93/6
Total Students in Sample	54	54	54	54	54	54

At first glance, it would appear that little has changed. The overall scores (a composite of text quality, calibration proficiency, accuracy of peer reviews, and self-assessment) show no meaningful variance from PDS 1 to PDS 2. The same can be said both for the text ratings given by peers and for the reviewer proficiency rating derived from the calibration exercise. However, recall that PDS 2 had a higher degree of difficulty:

Table II shows the overall grade and RCI remained constant from PDS exercise 1 to PDS exercise 2. Also, this table shows a modest 4% increase in the text rating from PDS exercise 1 to PDS exercise 2. These results are significant, due to the increase in difficulty of the assignment from PDS exercise 1 to PDS exercise 2. This same trend is seen in the Product Technical Description exercises 1 and 2.

USING CPR RESULTS TO SATISFY ABET ASSESSMENT OF LEARNING OUTCOMES

This project was started with the pragmatic emphasis to address EC3(g) (ABET Engineering Criterion 3-g): "ability to communicate effectively." Driskill [4], in examining how ABET (g) is addressed in available ABET accreditation plans, noted little evidence in the literature that assessment plans incorporate modern rhetoric pedagogy, contemporary discourse analysis, or the fundamentals of communication theory in their expectations for writing in an engineering education. Thus, the development of a rich definition of "communication" and measuring "effectiveness" by a set of carefully thought out exercises would be needed to assess EC3(g) (ABET Engineering Criterion 3-g): "ability to communicate effectively".

From our preliminary research on the PDS and PTD exercises we feel that these exercises do demonstrate our compliance with EC3(g). Also, we believe the RCI data indicate the richness of implementation associated with the "writing as thinking" approach to teaching [5]. In other words, from the data we may infer that the student learned. The following description, performance criterion and analysis are included from our most recent ABET report.

ABET g: an ability to communicate effectively.

- <u>Description</u>: graduates will demonstrate an ability to communicate effectively with written reports.
- <u>Performance Criterion</u>: 70% of student written reports have a low percentage of mistakes and normally contain an executive summary, social impact statement, project technical description, and project design specification.
- <u>Analysis</u>: This performance criterion is being satisfied.

ECE362	AY 03-04	ECE	AY 04-05	ECE	AY 05-06	ECE
ABET g	Yes	N	Yes	N	Yes	N
Annotation	NA	NA	87%	70	87%	78
Project Design Specification Initial	79%	56	81%	48	92%	78
Project Design Specification Final	73%	56	84%	70	72%	78
Project Technical Description Initial	NA	NA	77%	70	91%	78

Project Technical Description Final	80%	56	74%	70	84%	78

Our premise, essentially that writing within the educational process should be treated as crystallized thought – falls naturally out of the call for a more sophisticated definition of EC3(g). Based on the ideas of noted learning theorists, the "writing as a way of learning" approach to pedagogy holds that placing ideas into language mediates higher-order intellectual activities that are essential to mature thinking. Indeed, practitioners who have pursued the notion that writing is a heuristic for cognition report their students to be more actively engaged in learning and also find improvements in critical meta-cognitive abilities (or thinking about one's own thinking).

We also have found that addition ABET criteria can be satisfied. The following description, performance criterion and analysis are included from our ABET report for items ***j*** and ***i***.

ABET j: a knowledge of contemporary issues.

- Description: demonstrate an awareness of how the problem is affected by social concerns and trends
- Performance Criterion: 70% of student projects in ECE362 define the technical problem and demonstrate the link between it and social concerns/trends.
- Analysis: This performance criterion is being practically satisfied. However, all students do a Social Impact Statement using the IEEE Code of Ethics for their proposals. We will add an additional assignment earlier in the term to amplify the importance of this topic.

ECE362	AY 03-04	ECE	AY 04-05	ECE	AY 05-06	ECE
ABET j	Yes	N	Yes	N	Yes	N
Social Impact Statement using IEEE Code of Ethics	63%	56	71%	70	80%	78

ABET i: a recognition of the need for, and an ability to engage in life-long learning.

- Description: perform a literature search/gather information via library/internet
- Performance Criterion: 70% of student work has 3 independent references provided with analysis of each to support design recommendations.
- Analysis: This performance criterion is being satisfied.

ECE362	AY 03-04	ECE	AY 04-05	ECE	AY 05-06	ECE
ABET i	Yes	N	Yes	N	Yes	N
Annotated Bibliography of sources and references	NA	NA	87%	70	84%	78

- Description: ability to obtain and use technical data on components and subsystems

- Performance Criterion: 70% of students reported they used at least 1 source of information.
- Analysis: This performance criterion is being satisfied at present. However, all CPE students do perform patent research but many failed to use the patent research in their proposals. We will add an additional assignment to assess the value of the patents found relative to the proposal topic.

ECE362	AY 03-04	ECE	AY 04-05	ECE	AY 05-06	ECE
ABET i	Yes	N	Yes	N	Yes	N
Intellectual Property, patent research	77%	56	81%	70	71%	78

FUTURE WORK

From our preliminary work, CPR is proving a very effective tool for presenting an engineering design process, teaching multi-staged writing, encouraging students to develop higher-order reasoning processes, and capturing student outcome data. Additional research and data analysis is underway which better frame the effectiveness of CPR as a tool for ABET. Also, the Circuit's CPRs have been tested once with a pilot group of students. The results of these tests have been used to redesign these CPRs and they will be tested again in the Fall and Winter of 2007-2008.

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