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Assessing Engineering Design Experiences using Calibrated Peer Review™*

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We report on the assessment of the design experiences that students have in their electrical or computer engineering programs. Calibrated Peer Review™ (CPR) is the tool used for this assessment. CPR is an online-tool with four structured workspaces that perform in tandem to create a series of activities that reflect modern pedagogical strategies for using writing in the learning process. The learning materials that were developed for guiding students through an engineering design experience serve as the data for assessment.

Keywords: engineering design; peer-review; technical communication

1. INTRODUCTION

OVER THE LAST FOUR YEARS, the authors have collaborated on using a 'writing to learn' pedagogy in a junior-level engineering design course. Our thesis is that writing is thinking in print, but thinking from the point of view of the client or reader. When students write with others in mind, they give their ideas the critical attention needed to create an effective document. In addition, students need multiple opportunities to write and develop their communication skills [1].

Calibrated Peer Review™ (CPR) [2] is the tool used for this assessment. CPR is an online-tool with four structured workspaces within CPR that perform in tandem to create a series of activities that reflect modern pedagogical strategies for using writing in the learning process.

- *Task*: Students are presented with a challenging writing task, with guiding questions to act as scaffolding for the demanding cognitive activities.
- *Calibration*: Students read through three 'benchmark' samples and assign each a score based on a series of evaluative questions (a rubric). Students are then given a 'Reviewer Competency Index—RCI' from 1 to 6, based on their demonstrated competency in these exercises. This segment mitigates the common objection to peer review in the undergraduate classroom: that the experience reduces itself to the-blind-leading-the-blind.
- *Peer Review*: After becoming a 'trained-reader'—and being assigned a RCI—students read and provide written feedback on three anonymous peer essays using the same rubric as that used in the calibrations. Students also assign each essay a holistic score from 1 to 10.
- *Self-Assessment*: As a final activity, students evaluate their own essays. As with calibration and peer review, students use the same 'rubric' (set of performance standards for the task). Having 'trained' on benchmark samples, and then applied their expertise in evaluating peer text, students now engage in a reflective, final activity by assessing their own submission. Students are encouraged at this time to make comments to themselves (also available to the instructor) that capture the evolving insights they have gained in the previous two segments. They are also invited to reflect on whether they have gained a deeper level of understanding for the assignment and its outcomes.

2. SATISFYING ABET

Driskill [3], in examining how EC3(g) (ABET Engineering Criterion 3-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): 'ability to communicate effectively.' Therefore, the ECE Department at Rose-Hulman Institute of Technology (RHIT) developed a set of

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CPR exercises to help our students develop proposals for their senior design projects. The following CPR exercises are used:

CPR 1: What is Intellectual Property: This CPR introduces IP in the form of patents, trademarks, industrial designs (trade secrets) and copyright law to the students. Patent protection is the major focus of this CPR.

CPR 2: What is an Annotated Bibliography: This CPR introduces students to research using the annotated bibliography. The reason that the annotated bibliography is used, is that it adds descriptive and evaluative comments (i.e., an annotation), assessing the nature and value of the cited works.

CPR 3: Market Analysis: The students are introduced to two methods of market analysis coupled with project idea generation. These two methods are augment or bi-associate projects.

CPR 4: Product Design Specification: A Project Design Specification (PDS) is a document that 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: This CPR requires the students to reflect on their proposed project and write a social impact document using the IEEE Code of Ethics [4] as the rubric. For this assignment the students write one or two pages about the impact of their project on society.

CPR 6: Project Technical Description: The students produce their first draft of the project technical description using the information from the previous CPRs. The project technical description should provide a concise explanation that is not overly technical, while frequently emphasizing the key benefits and incorporating appropriate visual elements. Therefore the three essential elements of the project technical description are

1. Description: It is important to start the description with a very concise description 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 is usually helpful for the reader.
3. Key Benefits: State the key benefits of the product early. The use of bullet points is ideal. Then conclude stating the key benefits again in a paragraph form.

CPR 7: Project Technical Description, Again: The students produce their first draft of the project technical description using the information from the previous CPRs. The students next take the feedback from CPRs 1-6 and rewrite their project technical description with these specific elements:

- Does the project technical description tell the reader what the product does in the opening paragraph or sentence?
- Does the project technical description use concise and precise sentences along with concrete words to explain the product?
- Does the project technical description use visual elements to help explain the product?
- Does the project technical description present the key benefits of the product early in the description?
- Does the project technical description present an analysis of any competitors?
- Does the project technical description include an explanation of how the parts fit and function together?
- Does the project technical description conclude with the key benefits of the product in paragraph form near the end of the description?
- Does the project technical description convince you that this project can be done?

CPR 8: Product Design Specification, Again: A PDS is a document that will change substantially over the length of the project. There are many factors that will cause a PDS to change. But the one factor that will have the greatest impact is the development of a deeper understanding of the project. 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 reflect a deeper understanding of the team's project. The PDS is reviewed again using the following questions:

- Is a function list given with a short description for each project-function?
- Are performance specification given for each function?
- Is the operating environment for the project given?
- Are specifications provided relating to the operating environment provided?
- Are target technologies identified to meet all of above?

CPR 9: Social Impact Statement, Again: This CPR requires the students to reexamine their proposed project and rewrite their social impact statement using the IEEE Code of Ethics as the rubric. Especially focusing on item 1 of the IEEE Code of Ethics:

- 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;

The students also use the NCIIA E-Team RFP [5] as a format guide for the project technical description.

Table 1. Student CPR results

Name	Overall rating Out of 100	Text rating Out of 10	Reviewer Competency Index (RCI) 6 (best)–1 (worst)	Finished	Viewed results
1.	73.00	7.33	4	Yes	Yes
2.	90.00	8.33	4	Yes	Yes
6.	89.20	4.60	6	Yes	Yes
7.	–	–	–	Not started	No
15.	55.33	6.00	4	No	Yes

Table 2. CPR results from product design specification exercise

PDS	PDS 1 Overall rating	PDS 1 Text rating	PDS 1 RCI	PDS 2 Overall rating	PDS 2 Text rating	PDS 2 RCI
Class averages	91.91/100	7.78/10	5.02/6	93.02/100	8.13/10	4.93/6
Student sample	54	54	54	54	54	54

3. CPR PROVIDES DATA

A tool that is able to aid in the assessment of writing quality and cognitive level is a necessary step in the measurement of communications outcomes [6, 7]. CPR—with its emphasis on writing as a vehicle for thinking—offers the *means* for a less superficial definition of EC3(g) (an ability to communicate effectively) as well as the *methods* for collecting outcomes from which learning can be reasonably inferred. To support this claim, we offer data that was prepared for our successful 2006 ABET visitation.

Calibrated Peer Review collects data on thirteen different variables. For example, Table 1 illustrates the type of data collected by CPR as students work their way through the four segments of the assignment.

First, in Table 1 students' names are listed alphabetically and numbered in the far left column (in this example, names have been removed for confidentiality). The Overall Rating numbers are totals from the categories of Task, Calibrations, Peer Review, and Self Review. The Text Rating is a Holistic Score (1–10) of the Average Weighted Score given by three classmates on the submitted communication artifact. The Reviewer Competency Index (RCI) is an algorithm used to weight student ratings of classmate's text during the Peer Review phase [8, 9].

Second, each student is assigned a score based on their performance on the calibration essays. This score is reported as the 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) [8, 9].

During the Spring Quarter of 2006, 54 students participated in the PDS exercises 1 and 2. PDS-exercise-1 was a preliminary PDS and PDS-exercise-2 was the final PDS. See Table 2.

- The rating rubric for PDS exercise 2 was increased in difficulty from PDS exercise 1. See the above descriptions of CPR 4, Product Design Specification and CPR 8: Product Design Specification, Again.
- The text rating is based on calibration essays. The calibration essays all come from past projects that were successful and well written.
- The overall rating rubric was not changed from PDS exercises 1 to PDS exercises 2.

Table 2 shows that the overall rating 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 meaningful and trending upward because of the increase in the 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.

Third, for ABET g, both a description and a performance criterion were developed. Then the data from several CPR exercises were compiled and analyzed. Table 3 gives the results for several years.

ABET g: an ability to communicate effectively.

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

4. ADDITIONAL ABET CRITERIA

Additional ABET criteria were assessed using CPR. ABET j, ABET i, and ABET f. The descriptions, performance criteria, and analysis are included below and were taken from the ECE Department's ABET report.

ABET j-1: a knowledge of contemporary issues.

- Description: demonstrate an awareness of how

Table 3. CPR-derived assessment data for ABET g

ECE362	AY03-04		AY04-05		AY05-06	
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

Yes*: Percentages meeting the standard. n**: Number of students' responses.

Table 4. Additional CPR-derived assessment data for ABET

ECE362	AY03-04		AY04-05		AY05-06	
ABET Criterion and Description	Yes*	n**	Yes*	n**	Yes*	n**
ABET j-1: Social Impact Statement	63%	56	71%	70	80%	78
ABET i-1: Annotated Bibliography	NA	NA	87%	70	84%	78
ABET i-2: Intellectual Property	77%	56	81%	70	71%	78
ABET f-1: Social Impact Statement	63%	56	71%	70	81%	78
ABET f-2: Students did peer feedback of their Social Impact Statement	55%	56	67%	70	46%	78

Yes*: Percentages meeting the standard. n**: Number of students' responses.

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.

ABET i-1: 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 three independent references provided with analysis of each to support design recommendations.
- Analysis: This performance criterion is being satisfied.

ABET i-2: a recognition of the need for, and an ability to engage in life-long learning.
- Description: ability to obtain and use technical data on components and subsystems
- Performance Criterion: 70% of students reported they used at least one source of information.
- Analysis: This performance criterion is being satisfied at present. However, all ECE 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.

ABET f-1: an understanding of professional and ethical responsibility.
- Description: be aware of the requirements for processional licensure
- Performance Criterion: 70% of student work describes an application of a professional code of ethics related to ECE with a clear connection between the code provision and the application.
- Analysis: This performance criterion is being satisfied. All ECE 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.
- Note: ECE students do a social impact analysis of their proposed projects in ECE362 using the IEEE Code of Ethics as their guide.

ABET f-2: an understanding of professional and ethical responsibility.
- Description: have understanding of professional and ethical responsibility
- Performance Criterion: 70% of student work describes an application of a professional code of ethics related to ECE with a clear connection between the code provision and the application by writing a Social Impact Statement using the IEEE Code of Ethics.
- Analysis: This performance criterion is not being satisfied at present. This assignment occurs in the last week of the quarter and not all students complete the peer feedback since it has minor impact on their grade. This information was obtained by interviewing students. We will add an additional assignment and place them earlier in the term.

Table 4 represents data for three academic years as demonstrated by five of the CPR exercises, as described above. The data collected by the CPR software was used to determine whether or not an individual student meets the performance standard. We note that the rich set of data being collected in situ during a CPR assignment is a highly efficient and objective method of providing an outcome-based assessment.

5. CONCLUSIONS

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 that better frames the utility of CPR as a tool for ABET. Finally, CPR was successfully used—along with other assessment tools—to demonstrate outcomes assessment for the Electrical and Computer Engineering programs at Rose-Hulman Institute of Technology.

The authors have over six years experience using CPR. Furthermore, they have presented findings both at the Annual ASEE Conference and at Frontiers in Education. Calibrated Peer Review helps to integrate writing into engineering courses without adding additional burdens to an already full course syllabus.

The authors invite those interested in setting up a 'community of practice' for sharing expertise on CPR to visit http://www.rose-prism.org/files/CPRwebsitebrochure.pdf. For directions on how to join an emerging online community of engineering educators using CPR, please e-mail patricia.carlson@rose-hulman.edu.

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