Incorporating Student Peer-Review into an Introduction to Engineering Design Course

Patricia A. Carlson¹, Frederick C. Berry², David Voltmer³

Abstract – We report on a project to improve the teaching of engineering design at the junior level. Peer review of student work is an integral part of collaborative learning and reform-driven engineering education. Yet successfully implementing this pedagogical technique requires significant amounts of instructor and class time. Furthermore, if adequate formative assessment does not emerge from peer review, the experience may devolve into “busy work” in the eyes of the student. Here, we give early results from an NSF-funded study using Calibrated Peer Review (a web-delivered, collaborative learning environment) to enhance learning in engineering design.

Index Terms – computer-mediated learning, engineering design, peer-review, technical communication

TO ENGINEER IS TO DESIGN

Ideally, all courses in the engineering curriculum should address concept-building and problem-solving. However, “design” is the essence of modern-day engineering: “design, above all else, defines the difference between an engineering education and a science education” [1]. While differences in approach are evident, most design courses share a common framework, as described below.

All design courses require students to rely upon a body of enabling knowledge from science and mathematics to complete learning tasks. Also, virtually no course lacks a product (usually in the form a working prototype of the idea being developed, accompanied by appropriate types of professional documentation).

Courses may include a set of design formalisms, or strategies for structured problem-solving that constitute the “science” of engineering design. (How rigorously these methods are adhered to may depend upon local conditions.) “Constraints” in the design process are the contextual limitations, in the form of functional expectations, manufacturability, human factors requirements, socio-political issues, and the like.

“Creativity/Invention” now receives increasing attention in modern design education, even though its attributes are difficult to rationalize into a methodology or a comprehensive pedagogy. Add to this already “full plate” the fact that most design courses instruct students on how to work in teams, and the challenges of teaching engineering design become apparent.

We have taken some time to explicate a model of engineering design in order to demonstrate the nature of the demands, both for students and for faculty. We contend that well-planned communication assignments, strategically placed within the course will enhance definable attributes of cognitive growth, reflective judgment, and critical thinking.

REFORM-DRIVEN PEDAGOGY IN ENGINEERING DESIGN EDUCATION

For about two decades now, engineering education has been in the process of re-inventing itself. ABET’s revised requirements, changing realities of the workplace, and the growing awareness of language in the learning process all place added emphasis on writing in today’s engineering curricula. However, most instructors of engineering design believe themselves to be hard-pressed to incorporate additional writing assignments into courses already filled with content materials.

Also, most engineering design instructors may not have either the time or the expertise to provide commentary on student written work. Thus, the formative assessment for these assignments, so critical to learning, doesn’t emerge, and the experience may devolve into “busy work” in the eyes of the student. We report here on early results from an NSF-funded study using Calibrated Peer Review (CPR) – a web-delivered, collaborative learning environment for peer review of writing assignments – in a junior-level introduction to engineering design course.

Reviewing the literature, we found several reports of software to facilitate peer-review in engineering education. Eschenbach describes Peer Review, a web-delivered application (developed at Humboldt State University) using HTML “forms” to display instructor-authored questions about texts and to collect student responses [2]. From a different perspective, McGourty, Dominick, and Reilly describe using Team Developer™ to solicit peer feedback on several specific cognitive and behavioral dimensions of team-based learning [3]. Furthermore, most of the course management systems on the market today (WebCT™, BlackBoard™, or Angel™) enable instructors to create a session that will distribute student work, display a rubric (or set of performance guidelines), and collect peer commentary.

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In the remainder of this paper, we describe how we used Calibrated Peer Review (CPR), a free software platform that moves well beyond most web-delivered courseware products, as a cognitive tool for improving peer review.

I. Calibrated Peer Review as a Learning Tool

Developed by the Division of Molecular Sciences at UCLA, CPR™ is an excellent "learning environment" that creates an electronic, asynchronous, discipline-independent platform for creating, implementing, and evaluating writing assignments, without significantly increasing the instructor’s workload. Furthermore, the extensive data collected by the "environment" can be used to measure learning outcomes. In fact, the flexibility and versatility of the platform make it very appropriate as a fine-grained tool for ABET accreditation criteria.

CPR is a component of a large-scale, National Science Foundation supported project led by a team of educators at UCLA to develop a completely digitized, network-delivered Molecular Science Curriculum. The fully integrated CPR™ contains an assignment authoring tool for custom crafting of writing tasks and a library of edited assignments contributed by instructors from varied disciplines and institutions. Currently hosted at UCLA, the system draws from the model of manuscript submission and peer review in the conduct of scientific inquiry [4].

Four sequenced workspaces perform in tandem to create a series of structured activities that reflect modern pedagogical strategies for using writing in the learning process. A separate instructor interface and student interface provide customized reports on performance for individual assignments (see Figure 1).

![Figure 1: A Dynamic, Multi-Staged Learning Environment](image)

- **Task**: Students are presented with a challenging writing task, with guiding questions to act as scaffolding for the demanding cognitive activities. Students compose using a word processor, but upload the finished text as an HTML file. Some graphics and all tables are supported in the upload.
- **Calibration**: Students read through three “benchmark” samples and assign each a score based on a series of evaluative questions. Students are then given a “reliability index” 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 credibility weighting – students read and provide written feedback on three anonymous peer essays using the same rubric as given 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 document. As with calibration and peer review, students use the same “rubric.” 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.

**ECE 362: Engineering Practice as an Introduction to Design**

Most engineering programs have some type of capstone design experience. At Rose-Hulman Institute of Technology, the Electrical and Computer Engineering Department (ECE) has taken this a step further by requiring a junior-level course (ECE 362: Engineering Practice) which teaches the fundamentals of design before the students start their capstone experience.

ECE 362 is – for the most part – a technical writing course. The concepts of research, project design specifications, high-level design, detailed design, work breakdown schedules, budgets, and teaming skills are taught. All activities in the course culminate in a formal proposal for the senior, capstone design project.

Students work in teams, and the instructors enact a pedagogy that draws heavily from the insights of *Active Learning: Cooperation in the College Classroom* [5] and *How People Learn: Brain, Mind, Experience, and School* [6]. Student collaboration and peer-review are critical to the success of the course.

CPR sessions are interspersed throughout the ten-week course. Each assignment is a component of the final proposal. The CPR sessions are sequenced and tailored to maximize collaborative learning through peer review. Table A summarizes the six principal assignments for the course.
**TABLE A: CPR ASSIGNMENTS FOR ECE 362**

<table>
<thead>
<tr>
<th>Assignment Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is a Patent?</td>
<td>Annotated bibliographic entries for five patents on devices similar to the student’s proposed project</td>
</tr>
<tr>
<td>Market Analysis</td>
<td>Based on research, indicate target demographics, needs assessment, market dynamics, and major competitors</td>
</tr>
<tr>
<td>Product Design Specification (PDS)</td>
<td>A definitive statement for the design team giving the requirements and constraints that the new design must fulfill.</td>
</tr>
<tr>
<td>Product Technical Description</td>
<td>Distinct from the PDS, this document describes salient physical characteristics of appearance and composition.</td>
</tr>
<tr>
<td>Social Impact Statement</td>
<td>Considers the larger context / ramifications, which may include political, social, ethical, legal, professional, or physical dimensions.</td>
</tr>
<tr>
<td>Product Development Proposal</td>
<td>Consolidation of Parts into a Whole: Upload the final project proposal representing the culmination of previous five assignments.</td>
</tr>
</tbody>
</table>

II. Peer-Review in the Learning Process

Not so long ago, engineering was viewed as applied science. The curriculum was filled with exercises in scientific fundamentals, applied to what might be termed classical engineering situations. Much time was spent in laboratories, working through standard exercises in data collection and analysis. Unlike the teaching that now characterizes medicine or the law, engineers were taught in an environment curiously devoid of a sense of practice.

Over the years, this “decontextualization” caused distortions in attitudes and values, along with graduating engineers who had little exposure to the types of professional maturity and judgment they would need from the very first day they stepped into the work world.

Reform-driven engineering education incorporates various types of collaborative learning experiences. Such pedagogy yields a number of gains for modern engineering education. Peer review is an especially rich pedagogical technique, whose instructional objectives should include:

- Enhance students’ meta-cognitive abilities in a complex process by fostering, higher-order activities, such as those represented by the upper levels of Bloom’s Taxonomy [7]
- Encourage students to develop mature, professional behaviors: the student progressively moves from depending on external, “teacher-centered” authority to a more self-assured ability to reconcile multiple perspectives, to tolerate ambiguity, and to reflect on the process itself (meta-cognition)
- Encourage students to develop the social skills needed to work with a team through the sharing of ideas, the ability to provide meaningful feedback, and the ability to accept peer critiques.

Unfortunately, integrating effective peer-review sessions into a course requires much effort on the part of the instructor. Karen Spear [8] enumerates several of the pitfalls associated with peer-review of writing, no matter what the course content:

- Confused expectations about the group’s purpose and the individual’s role in it;
- Inability to read group members’ texts analytically;
- Misperceptions about the nature of revision and of writing as a process;
- Failure to work collaboratively with group members;
- Failure to monitor and maintain group activities (pp. 17-18)

Despite its enormous potential, peer-review suffers from the common criticism that – without labor-intensive scaffolding and time-consuming mentoring – the process frequently reduces itself to “the blind-leading-the-blind.”

**THE BENEFITS OF CALIBRATED PEER-REVIEW**

Elsewhere we have examined how CPR’s in-situ data collection provides assessment for learning outcomes [9]. Here, we consider how CPR helps to overcome the most common drawbacks for collaborative learning involving peer-review.

I. Students Have Widely Varying Skills Level

Having students critically analyze their classmates’ work assumes that all students have the ability to effectively judge the assignment under consideration and to offer useful comments for improvement. Sadly, experienced instructors know that this is not the case. Asymmetrical skill levels can result in

- Discomfort or defensiveness during the peer-review process for some students
- Less-than-candid behaviors evolving during the collaboration process (such as, mutual admiration societies, superficial engagement, off-task commentary)

In a traditional classroom, countering these pitfalls requires a significant investment of instructor preparation and use of precious class time.

Calibrated Peer Review helps by mediating the entire process of peer review. Especially important, each student goes through the calibration training session, in which she reviews three “benchmark” responses to the assignment (typically of high, medium, and low quality) and answers a set of questions that assess performance aspects of each piece. Students receive guidance when they answer incorrectly.

After “calibrating,” each student moves on to evaluate submissions by three peers. (Reviewers and authors are anonymous. However, in the instructor’s report, each individual is identified.) At the end of the sequence, each author looks at her own submission (self-assessment) and performs the same analysis that she did on peer submissions, with the opportunity to do meta-cognitive reflection.
Also alleviating the problems of varying skills levels, each student receives a rating of her achievement during the calibration (from 1 to 6). This number is used to “weight” the impact of her scoring of classmates’ submissions.

As further indication that CPR addresses the “varying skills” issue, both on an experiential level and on an empirical level, we have found that CPR sometimes helps to “level the playing field” for the less academically talented students.

For example, using the data collected by CPR, we looked at all six of the CPR sessions in ECE 362 (as described in Table A), and we plotted the mean of the variable “revdev” (deviation in scores for reviews performed by each student) for all six sessions.

To this analysis, we added a dimension of how students’ initial aptitude affects performance. We did a median split on all six sessions, using the variable “rating of text submission” as an indicator of the students’ pre-calibration understanding of the assignment.

Keep in mind the sequence of events within the CPR environment. The student reads an assignment, produces a text artifact, and then is trained on what an “expert” would look for in evaluating the assignment. After the training, the student then applies this learning to a review of peer-written submissions (producing the variable “revdev”). Thus, how well a student’s submission is rated becomes a proxy-measure of how well the student performed before the training in the calibration workspace.

Because “revdev” is a measure of average deviation, the smaller the number, the better the student has performed. As can be seen in Figure 2, these preliminary results do not indicate a clear and consistent negative slope for either ability group (as determined by the median split). Nevertheless, we found three observations of interest:

- First, of all the assignments, the writing prompt in assignment #2 (Market Analysis) seems to dampen whatever effect varying initial competency had between the two aptitude groups.
- Second, assignment #4 (Product Technical Description) clearly treated the two aptitude groups very differently (indicating an aptitude-treatment interaction). The variance between the high aptitude’s and the lower aptitude’s ability to apply what was learned in the calibration training caused us to re-examine the calibration phase of assignment #4.
- Third, the training in assignment #6 (Product Development Proposal) appears to have worked well for both groups, but seems to have been especially effective with the lower aptitude group.

We are examining the training in each of these assignments to determine how best to revise the materials for upcoming courses. Demonstrating that an assignment was effective for all students -- and was especially effective with a low-ability group -- indicates robust instruction using the CPR environment.

II. Students Get/Give Only Sketchy Formative Feedback and Consequently View the Process as Worthless “Busy Work”

While educational theorists and practitioners alike promote the value of having students learn from other students, more telling are studies that done on how students view the process. Simkin & Ramarapu report that students feel comfortable with peer-reviews of their written materials provided a procedure to promote fairness and rich response has been instituted [10]. Rafiq & Fullerton found that students teams who kept highly-focused diaries on members’ performance were more engaged in all aspects of the course [11]. In general, students are least satisfied with peer evaluation methods that produce superficial, vague, glib, or harsh commentary.

CPR provides learners with two types of detailed formative assessment: quantitative (the numerical ratings given by peers on various aspects of the assignment) and qualitative (the narrative comment peers write to justify particular scores). Each is explained below.

Quantitative Ratings: The complex algorithms of the CPR system provide each student not only with numerical evaluations of her submitted text but also an indication of how well she evaluated the work of others. The student also receives a “reader confidence index” score indicating how qualified she is as a reviewer, based on performance during the training (or “calibrating”) segment of the session.

These are unique features of CPR; the system is able to indicate both the reliability and the validity of individual’s peer-review contributions. Such feedback both motivates students to improve their scores and alleviates the anxiety expressed by students that “unqualified” raters are negatively affecting their grades.

Figure 3 – the student results report – shows how performance information is returned to students. Students see how well they performed in evaluating three of their peers (top level of the interface). They also get more detail on each of the performance criteria (five for this particular assignment). The student also sees the summative, holistic score (from 1-
Qualitative Comments: As motivating as the quantitative feedback is, the advice and observations provided by peers becomes invaluable in guiding students’ growth and improvement. By clicking on the response to each rubric item, the student author is taken to what the peer reviewer said to justify the numerical evaluation.

We have found that by carefully crafting the performance questions in the rubric, we are able to elicit peer commentary exhibiting characteristics of the three higher levels of Bloom’s Taxonomy:

- **Analysis:** Breaking down objects or ideas into simpler parts and seeing how the parts relate and are organized
- **Synthesis:** Rearranging component ideas into a new whole
- **Evaluation:** Making judgments based on internal evidence and external criteria.

Table B provides some sample student commentary taken from assignment #3: Product Design Specifications. They illustrate how the guided-inductive nature of the CPR embedded rubric elicits focused evaluation. Students move beyond description/explanation (a lower level cognitive skill) toward using discerning judgment in order to solve problems.

### Table B: Examples of Qualitative Feedback for PDS

<table>
<thead>
<tr>
<th>RUBRIC ITEM</th>
<th>STUDENT SAMPLE RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Is a function list given with a short description of each project-function?</td>
<td>NO -- Explanation: Components are given, but specific functions are not described. This needs to be organized into a list so it is easier to read. There is a lot of information here that is not needed in the PDS.</td>
</tr>
<tr>
<td>(2) Are performance specifications given for each function?</td>
<td>YES: Explanation: some of the functions don't need specs, but for example &quot;disc title memory&quot; - 24 titles/ 8 letters, that's a good example of performance spec for a function.</td>
</tr>
<tr>
<td>(3) Is the operating environment for the project given?</td>
<td>YES -- Explanation: May want to expand on existing cars, what type of temperatures will your device need to endure? Having a different type of tail light means the lights will have to endure some sort of corrosive tests.</td>
</tr>
<tr>
<td>(4) Are specifications provided relating to the operating environment?</td>
<td>NO -- Explanation: In a car there are government regulations even relating to a non safety-critical system such as tail lights. Look at the Federal Motor Vehicle Safety Standards. The one that should apply to brake lamps is FMVSS 108: Lamps, Reflective Devices and Associated Equipment. Also, you will need to probably have some sort of failsafe scheme to assure that a failure is detected. This is not as important as your device cannot by itself cause a potential hazard, but if your device says there is no problem and doesn't warn the driver because of a device failure, that seems like you are opening yourself up to problems such as a lawsuit.</td>
</tr>
<tr>
<td>(5) Are target technologies identified to meet all of the above?</td>
<td>NO -- Explanation: There are a number of different transducers. Is this going to be one that measures brake pedal travel, or is this going to be brake force. Also, the brake travel is not a linear function when compared to the amount of actual decel on the car. From car to car this can vary greatly. Also, there is a large discontinuity at the point of booster run out. Another point is a number of cars already have some sort of brake pedal travel sensor, especially ones with newer brake control systems. Also, what type of technology is going to be used as an &quot;electronic tape measure&quot;? You can use Laser, Radar, or other systems. These can have advantages and disadvantages. Some of the laser based systems have problems in weather.</td>
</tr>
<tr>
<td>(6) How would you rate this text? (on a scale of 1 to 10)</td>
<td>5 -- Explanation: It is very brief and difficult to pull out information quickly. You might want to reformat it, add more detail, and discuss your environmental factors.</td>
</tr>
</tbody>
</table>
We have described some advantages of using CPR as a platform for integrating peer review into engineering education. However, any instructor considering CPR for course adoption will also want to know about such pragmatic issues as ease of use, return on time investment, and student reaction and learning gains.

- **Investment of Course Time**: Each instructor decides how much emphasis can (or should) be given to CPR assignments in a given course. A few caveats are appropriate here. First CPR sessions work best if the writing assignment is relatively short and compact (say, three, four, or five paragraphs). Second, the assignment should involve problem solving, critical thinking, or concept formation. Furthermore, the objectives of the assignment should be well-formulated and clearly reflected throughout the CPR session. In our several years of combine experience with the system, we have found CPR most appropriate for drafting key components of longer documents. On average, students in the pilot study worked directly with the CPR environment for no more than two or three hours per week. Given the return in learning, we believe the time is extremely productive.

- **Overhead for Instructors**: Authoring a CPR session is labor-intensive for the first couple of times. However, once the instructor builds up some expertise and a small library of adaptable assignments, the task becomes easier. Depending on the individual and the complexity of the assignment, a session may take four to five hours to prepare. In our experience, the return on investment comes in being able to treat written work seriously without burying oneself in stacks of grading or returning papers with copious commentary, which students may all-too easily ignore, misinterpret, or misplace.

- **Student Reactions**: Our students usually find the first CPR session challenging. Seldom – especially in an engineering course – have they been held accountable for the process of writing to this degree. (Even in classes where instructors require peer critiques, it is difficult either to mentor or to monitor students at this fine-grained a level.) However, our experiences show that over the ten-week quarter, students come to value the CPR experience. Because each CPR assignment highlights a critical component of the larger, final proposal, students learn the iterative nature of composing a quality piece of writing. They also come to trust their peers’ judgment and to value the guidance they receive from these fellow students. Anecdotal evidence suggests that almost all students are positive by the end of the course. Even those who struggle will admit that they better understand how to write a project proposal and that many of the nuances they have learned come from scrutinizing the submissions of fellow students. Also, a simple comparison between the final proposals from the same course as taught in prior years (without CPR) shows dramatic improvement.

We have found no system available today that duplicates the following powerful features of CPR as a complex, highly orchestrated cognitive tool for mediating peer review:

- The writing/review/reflection/revision process – often perceived as opaque and arbitrary by many students – is reified into a set of understandable “state transitions” through the robust “thinking frames” of CPR.
- Students are trained on what to look for in evaluating the specific assignments, improving the quality of student feedback, enhancing learner confidence, and promoting deep engagement in the process.
- After evaluating peer contributions, students can consolidate and apply their gains by reflecting on their own submission (in light of insights gained from examining materials from fellow students).
- The system handles all logistical issues: materials are stored and distributed in keeping with the sequence of the “thinking frame”; student submissions are randomly distributed and reviews are anonymous; powerful, built-in algorithms measure levels of performance at key stages in the process.

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