Project Summary: Implementing a Process Approach in Engineering Design Through Calibrated Peer Review

Background and Goals: The proposed project will implement an established process approach to support learning in capstone design. This work integrates (a) instruction in the process approach to design, (b) development of a measurement system that is aligned with instruction, and (c) assessment and evaluation of projects and project teams as they work on capstone design projects. The project addresses two essential needs: the need for results-based design education and the need for cost-effective approaches to design education. To accomplish project goals, the project team will adapt and implement two exemplary practices: the process approach to engineering design described in Product Design and Development by Ulrich and Eppinger (2004) and the Calibrated Peer Review (CPR) web-based tool developed at UCLA. Major project outcomes are:

1. CPR-based Instruction System. Develop 10 web-delivered modules that feature Calibrated Peer Review. Each module will be transferable to other schools and will align with the text by Ulrich and Eppinger (2004). Together with in-class instruction, the CPR modules will result in students who develop and use a process approach to design.

2. The Design Measurement System. Develop five valid, reliable, and transferable measuring instruments that measure quality in engineering design. The three dimensions of measurement are (a) transfer of learning (from instruction), (b) growth in the process approach during the project, and (c) quality of a project in terms of creating results.

3. Traditional Outcomes. Create local support (> 75%) for a process approach by college faculty and students. Publish six papers with at least two of these papers in archival journals. Create an extensive website that documents (a) the process approach to design, (b) transferable results (CPR modules and measurement instruments) that support instruction. Produce two MS graduates.

Challenges: This Type II Adapt and Implement proposal focuses on overcoming two barriers: building community within an institutional culture that is bound by the traditions of the last 35^+ years of educational practice, and developing a cost-effective approach to creating engineering graduates who can design with high levels of performance.

Intellectual Merit: The intellectual merit centers on alignment of instructional goals, instruction that results in goal attainment, and embedded measurement of learning, performance along with growth in performance. One novel aspect of the measurement is that it will extend beyond the instruction, thereby providing data on transfer. A second novel aspect is that the measurement system will measure the alignment of learning with the ability to produce results for a client.

Broader Impacts: Modern enterprises stay in business by delivering results (products) that meet the needs of their customers. The design process is the process for meeting customer needs. Thus, the central need of modern enterprises, including universities, is for people with an effective design process. Attainment of the design process is a learning and growth issue. An educational system that guides people to grow effective design practices and process will provide extraordinary impact. This project will demonstrate that this outcome can be reached in a cost-effective way.

Implementing a Process Approach in Engineering Design through Calibrated Peer Review

We believe that the central role of the engineer in society is design. Design is "the process of devising a system, component, or process to meet desired needs." (ABET, 2004). Because of the seminal important of design, the capstone design course in an engineering curriculum can serve as a catalyst to elevate learning throughout the entire curriculum.

1. Results from Prior NSF Support

The NSF has generously supported the University of Idaho community through three recent grants (for details see www.webs1.uidaho.edu/wtp and www.webs1.uidaho.edu/ele). Some of the outcomes of these projects (attained or expected by July 2005) include best paper at the American Society of Engineering Educators (Zemke et al., 2004), 300 days of faculty development involving over 70 professionals, development of the professional community with over 30 members spanning eight disciplines, 22 papers published in American Society of Engineering Education and Frontiers in Education proceedings, and an M.S. and Ph.D. graduate.

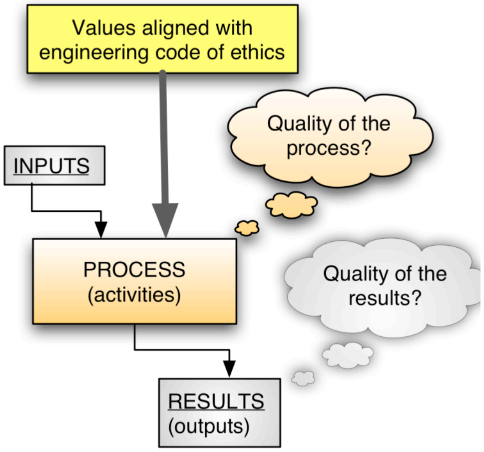

Figure 1. Concept of process

The major outcome from the NSF projects has been the development of a process approach (Beyerlein et al., 2003). We define process as a collection of interrelated and interacting steps that transforms inputs into results, Fig. 1. A process approach focuses simultaneously on the quality of end results and the efficiency of the process that led to the results. A process approach aligns/integrates five focus areas:

1. Community. A focus on building a community of practice that includes professionals, students, and professors who collaborate with a common focus on growing performance and creating results.

2. Results Orientation. A focus on defining challenging goals then committing to and attaining results.

3. Process Clarification. A focus on purposeful definition and documentation of the processes and practices used by the professional community.

4. Growth and Improvement. A focus on growth of each individual plus growth of the community in terms of continual evolution of process and practices.

5. Measurement. A focus on accurate perceptions of reality by the systematic use of valid and reliable data to support assessment, decision-making, and evaluation.

2. Present Situation and Needs

At the UI we have an outstanding capstone course (see http://seniordesign.engr.uidaho.edu) plus a team of committed faculty members who are highly active in engineering education. However, we are now at a point of crisis due to major financial cutbacks, a net loss of faculty, and a large gain in student enrollments. Thus, we are innovating and designing a next generation capstone course that will produce stronger community plus higher level learning with fewer resources. Three key needs are:

1. Process Approach. Colleges of engineering need a process approach for effective teaching of design. Similarly students need to learn a process approach to meet the needs of modern companies.

2. Efficiency. Engineering design courses need to be more cost-efficient.

3. Instruction. Teaching design in a way that produces high-level learning outcomes requires many years of experience plus extensive resources including curriculum, mentoring, materials, and time.

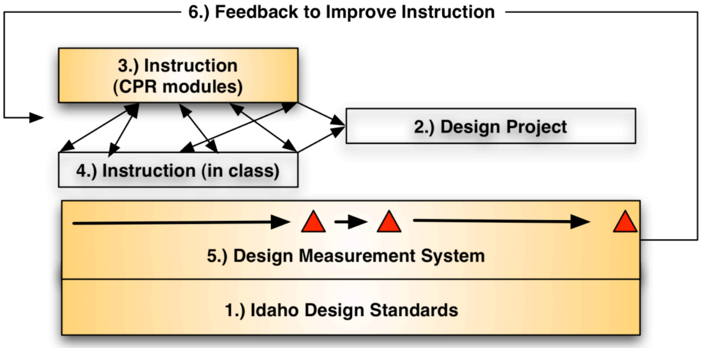

Figure 2. System-level design of the *next-generation capstone course*. Shaded regions show emphasis areas supported by this proposal. Numbers denote major systems.

3. System Level Design

The *next generation capstone course*, Fig. 2, is comprised of six integrated and aligned systems.

1. Idaho Design Standards. These are a written and measurable description of a high performance engineer in the design environment.

2. Design Project. The design project involves a project with industrial funding, a client, a significant financial investment by the client, and a need to deliver results that justify the client's investment.

3. CPR Modules. These modules are a set of ten web-based instruction packages built around the Calibrated Peer Review (CPR) tool. These modules will align with concurrent in-class modules.

4. Classroom Instruction. Classroom instruction will involve active learning that is designed following best practices.

5. Measurement System. The measurement system provides feedback to students. Feedback is descriptive, non-judgmental, student-centered information that helps students improve their performance. The black arrows in Fig. 2 show when students receive feedback. The measurement system provides evaluation. Evaluation is judgment of a product or performance against criteria with a well-defined scale of measurement. The red triangles in Fig. 2 show three major evaluations.

6. Feedback/Improvement System. This system provides data from students, project managers, and clients so that instruction and structure can be regularly improved.

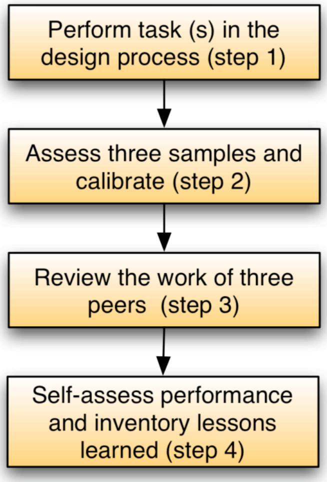

Fig. 3. Process used by CPR

4. Adaptation Sources

The first adaptation source is the Calibrated Peer Review (CPR) Tool from UCLA. The CPR process is shown in Fig. 3 (Furman and Robinson, 2003). In step 1, students are given an engaging task(s), they complete the task, and submit their engineering documentation online. In step 2, students assess three samples of student work by measuring the quality of the samples using criteria that are specified. The three samples are chosen to illustrate strong, developing, and weak performance. The CPR program calibrates students' peer review by giving them immediate feedback. In step 3, a student reviews work of three peers against specified criteria. In step 4, students receive their peer reviews, compare peer reviews with self-review, and document what they have learned.

CPR has several strengths. First, CPR manages schedule, collection of student work, training the students in peer-review, the peer review process, and the self-assessment of performance. This is strong because CPR modules, once created, can be used with very little instructor time or effort. Second, CPR is designed so that it is very difficult for students to play games in order to achieve high scores. This is strong because it allows faculty and students to align with a common goal of strong performance on tasks in the design process.

The third and main strength of CPR is that it leads to growth in cognitive level over time. CPR moves students from a reliance on authority because students are expected to assess their performance using criteria. As students grow over time, they begin guiding their work with criteria, thereby taking ownership of the quality of their own performance. Later on, some students will grow to where they begin "*inventing new criterion that describe quality*." This growth, also known as adaptive expertise (e.g. see Bransford et al., 2000) is a seminal indicator of an effective process approach.

Emerging evidence shows that CPR impacts learning. While CPR has only been available since 2001, it has been used in 408 colleges and universities (Who uses CPR, 2001), thus providing evidence that CPR aligns with many professors. CPR is described as a "*cognitive apprentice model*" by Carlson and Berry (2003). CPR's four steps act as mentoring stages that facilitate learning and help learners internalize strategies for later performance of similar tasks. This evidence suggests that CPR can be used to reduce barriers for non-traditional students.

The second adaptation source is the process approach to engineering design from Ulrich & Eppinger (2004). Evidence for the process approach is strong. The core practice of modern companies is based on process; for example, ISO 9000 (2004). "World class" companies such as IDEO (www.ideo.com) use the process approach. CPR modules will be created to teach the process approach. Design and development of the modules will follows the instructional design approach presented by Dick, et al. (2005). Examples of CPR modules are given in Table 1.

5. Idaho Design Standards

The standards are a written and measurable description of high performance engineering in the design environment. The standards have three themes:

1. Design Process. High performance engineers use a process approach for engineering design. The standards describe ten steps that are essential to design. These ten steps follow Ulrich and Eppinger (2004).

2. Integrated Professional Practices: High performance engineers add value to design projects by using key practices. The standards describe ten key practices. Examples of key practices include prototyping, ethical practice, and design review.

3. Team Process. High performance engineers use a process approach to develop self-growing teams

that attain high levels of collaboration. The standards describe six steps that follow Carr et al. (2005).

The standards have two important features. First, each component of each theme is written using observable behaviors. Second, quality for each specific component is described by written criteria. At present, the first draft of the standards is 75% complete.

6. The Design Measurement System

Table 1. Examples of CPR based modules

Design Process Overview. The context is designing an instrument to measure power from a horizontal-axis-wind turbine for a client (professor) and customers (students in a fluids course). The students will engage with tasks in the concept development phase of a project. The module terminal outcomes involve application of the process approach in the context of a real-world project.

Prototyping. The context involves using engineering analysis on an assignment for a supervisor (client). The problem is that the results of the analysis suggest a problem that will impact the end user (customer), but the supervisor wants this problem swept under the rug. The module terminal outcomes focus on the process of prototyping and ethical practice.

Assessment. A project team has developed an idea for a new product—this new idea is a glove-like device that will allow end-users to control the operations of an IPod device while snowboarding. The CPR task will involve reviewing the team's needs analysis and target specifications and providing the team with feedback. The module terminal outcomes focus on assessment plus defining a goal state with needs and specifications.

The Design Measurement System will be comprised of five instruments that are aligned with criteria in the Idaho Design Standards. An example of a measuring instrument is shown in Table 2. This instrument, developed following Dick et al. (2005), provides a way to measure quality in the *performance* of prototyping and quality in the *product*, which is the prototype itself.

Measurements will be **embedded** in the context of the projects and the instruction. Embedded means that measurements are built into the instruction and project so that nearly all students find them helpful and meaningful. In addition, embedded means that measurement reduces the net effort to deliver instruction or manage the project. We plan to develop five aligned measuring instruments:

1. Learning Checklist. This instrument (see Table 2 for an example) will be primarily used by students and by student teams during instruction. The purpose of this instrument is to help students learn to self-assess their learning and performance, to provide a gateway for mentoring, and to provide feedback to instructors on the efficacy of instruction.

2. Design Process Success Matrix. This instrument will be used by student teams during a project. This instrument, which will summarize the major steps in the design process, will provide structure plus criteria that help student teams take ownership of the design process. The purpose of this instrument is to foster team self-assessment, to provide structure to the design process, to provide a gateway for mentoring by the project manager, and to provide the project manager with feedback on how effectively the team in managing their project.

3. Professional Growth Portfolio. This instrument will be used by used by individual students during a

project. The portfolio will be comprised of weekly self-reflection (20 minutes/week) on growth in the design process. The instrument will be a rubric that measures growth as compared to the criteria in the Idaho Design Standards. The purpose is to foster growth through self-reflection, and to provide the instructors with a rich description of the student growth in their own words.

4. Front End Project Evaluation. This instrument, used by clients and course instructors, judges phase 1 (problem formulation, concept generation, concept selection) of a project.

5. Design Project Evaluation. This instrument, used by clients and course instructors, judges the final results of a design project.

Table 2. Example of criteria for effective prototyping using the Learning Checklist Instrument.

Prototyping—*Criteria that determine quality*	Yes	Partly	No
Process Criteria			
• The prototype is justified by a significant project need.			
• A clear goal state for the prototype is defined early in the process.			
• A written plan is created and followed.			
• Appropriate learning (texts, experts, etc.) is used to add value.			
• The level of approximation (focused versus comprehensive) is right.			
• Appropriate balance of analytical versus physical.			
• The level of challenge (neither too hard nor too simple) is right.			
Results Criteria			
• Engineering analysis is validated.			
• Engineering experiments are validated			
• The prototype is as simple as possible.			
• The time spent on the prototyping effort is low.			
• Results of the prototype strongly benefit the project.			

7. Project Evaluation

Project evaluation will be built into the project from the start. Since the lead academic officer from the university (A. George) is on the project team, our institution will know our evaluation results. Major steps of the evaluation plan are:

1. Define the three most important project outcomes. See Table 3 for a rough draft.
2. For each outcome, list measurable criteria. This is not yet done, but Table 3 gives some of the aspects of these criteria.
3. For each criterion, select a metric plus a target value. At the end of phase 1, lock the target values.
4. Once every 6 weeks, compare project intermediate results against the criteria in the evaluation targets, inventory strengths (what's working), create an action plan to improve weaknesses, and implement the action plan.
5. Through the first two phases of the project, gather stakeholder input. By the end of phase 2, make sure that the CPR and measurement systems align with student values, priorities, and needs. Repeat for professors and industry partners.
6. At the end of the project, evaluate by comparing the final results with the evaluation targets.

Table 3. Evaluation Targets
Enriched Learning and Growth (Target 1). Students can give a valid definition of key terms. Students can explain each main task in the design process. Students can execute a task in the design process. Students can self-assess their process for a task. Students can self-assess the output (end result) of a task. Students can describe their growth. Students follow the design process. Students adapt the design process to fit the project needs.
Strong Community at University of Idaho (Target 2). Students believe in and support the process approach to design. Students find CPR modules appealing. Students find CPR modules relevant. Professors believe in and support the process approach to design. Professors find CPR modules appealing. Professors find CPR modules relevant. Repeat criteria for industry participants (project sponsor + advisory board).
Transfer of Project Results to the External Community. (Target 3). Project web is well organized. CPR modules meet the needs of design instructors in many contexts. Measurement instruments meet the needs of design instructors in many contexts.

8. Project Dissemination

Dissemination will be built into the project from the start. We will follow the step-by-step process presented in proposal section 7. The dissemination will target two groups of people.

Local Dissemination. The target audience is College of Engineering Faculty and University of Idaho Administration. The method of dissemination is presentation and short workshops that are aligned with ongoing activities such as faculty meetings. The purpose of this dissemination is to listen to the voice of the traditional professors, to build shared understanding, and to create advocates for the process approach to engineering design.

Practitioner Dissemination. The target audience is the national community of faculty who teach design. The method of dissemination is workshops at national meetings. The purpose of dissemination is to listen to voice of the practitioners, to modify CPR modules and measuring instruments as needed, and to share these resources with the community.

9. Project Plan

The project has three main outcomes:

1. CPR-based Learning System. Develop 10 web-based modules of instruction that develop a process approach to engineering design. Each module will (a) communicate a goal for learning, (b) provide students with descriptive feedback, (c) motivate students, (d) create understanding of design as a process, (e) align with the Idaho Design Standards, (f) align with Ulrich and Eppinger (2004), and (g) be judged as exemplary by engineering professors in terms of content, relevance, and academic rigor.

2. Design Measurement System. Create and establish validity and reliability for the five measuring instruments described in proposal section 6. Gather and interpret data for one academic year.

3. Traditional Outcomes. Create local support (> 75%) among local students, faculty, and industry participants. Write six papers with at least two of these papers published in archival journals. Develop a comprehensive website that documents all aspects of the project. Execute the evaluation and dissemination plans described in proposal sections 7 and 8, respectively. Graduate two MS students.

To reach project outcomes, the project will be organized with phases, tasks and milestones:

Phase 1: Project Launch (August 1, 2005 to March 15, 2006)

Organize the Team. Set up all aspects of the team structure including the team contract, the team member assessment process, the project management system, project evaluation system, the team meeting process, and the team problem solving process.

Generate and Select Concepts**.** For CPR modules and measurement system, repeat at a deeper level the external and internal search processes, generate hundreds of solution options, assemble trial solutions, iterate, acquire data from simple experiments, iterate, evaluate solution options against criteria. Select the final solution ideas for CPR modules & measurement system.

Dissemination**.** Set up and execute the dissemination process as defined in proposal section 8.

Δ: Milestones for Phase 1. CPR and measurement system aligned with students. Project evaluation and dissemination plans on track. Two conference papers completed. Web structure completed and populated will current documentation. Comprehensive definition of (a) all parts of the CPR module system, and (b) all parts of the Design measurement system.

Phase 2: Design and Fabrication (March 15, 2006 to August 1, 2006)

System Level & Detail Design. Create a "block diagram" with specifications. Specify details and create documentation package that describes all aspects of fabrication.

Fabrication and Testing**.** Complete all modules and instruments. Test and fix problems.

Δ: Milestones for Phase 2. Project evaluation and dissemination on track. Two more conference papers completed. Website populated with current documentation. CPR and Measurement Systems completed and ready for full implementation with student population.

Phase 3: Validation and Project Closure (August 1, 2006 to June 1, 2007)

Implementation, Testing and Closure. Implement the CPR system and the Measurement System. Validate against design specifications. Gather and interpret data on student learning. Reach all project outcomes. Celebrate.

Phase ∞: Continuing Reform beyond Project Closure. The project plan targets long term sustainability. The degree of sustainability is based on three factors: the reform is being built into the local community, the CPR modules and measuring instruments can be quickly updated and improved, and data for improvement will naturally flow out of the embedded measurement system.

10. Project Team

The project team has the passion, experience, and expertise to reach the defined project outcomes. Beyerlein has national level prominence in engineering education, many years of leadership in capstone education, and a major role in the Pacific Crest Community (www.pcrest.com). George is the leader of the university institutional assessment and evaluation center and has more than thirty years of experience in assessment and evaluation. Druker is a highly successful writer, innovator, and instructor of technical writing. Elger, a passionate national level proponent of transformational change in engineering education, has taught design for many years, and has led three successful NSF projects.

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