Abstract
Over the past ten years the School of Engineering and Technology at Lake Superior State University has developed a strong industrial-based capstone senior design course sequence. An industrial company provides a design project, funding, and a company representative for this two semester-long course sequence. A key element of the capstone design course sequence is the interaction of the industrial customers, the company representatives, and students in a structured design review process. This paper discusses the philosophy, purpose, and value of the design review and how it fits into the engineering communication process with the customer. It also discusses the fit of the design review in the overall communication process that is common to engineers. Finally, the paper explains the evolution of an effective design review process that ties the industrial customer, students, and faculty together resulting in a quality product for the company. The paper will be of interest to faculty who teach in capstone design courses in engineering and technology. The paper has been developed with the assistance of industrial representatives and faculty that are teaching and administrating the senior design courses.

Introduction
During the late 1980s and early 1990s significant attention was being given to products produced and manufacturing processes used in the United States. Seminars, class sessions, and presentations were being given on methods to improve US products and processes. Industry was learning and adapting Dr. W. Edwards Deming’s statistical methods and principles. Noted speakers such as Tom Peters were writing books and providing lectures on “In Search of Excellence,” “A Passion for Excellence,” and “A Passion for Customers.” Similarly engineering educational institutions were working to improve their curriculum to address deficiencies in the educational process. In 1995, Dr. Christian Przirembel published “Integrating the Product Realization Process (PRP) into the Undergraduate Curriculum.” The document listed the top twenty elements of the PRP for entry level and experienced mechanical engineers. This list includes concepts on teamwork, communication, design, and design reviews.

The importance of design reviews is also understood by industries. The top twenty key elements of the PRP cite design reviews as number four in importance in the list of skills for experienced engineers. Another indication of the importance of design skills to industry is the offering of seminars such as “Design Reviews for Effective Product Development” offered by the Society of Automotive Engineers.
During the latter part of this time period the Accreditation Board for Engineering and Technology also developed Engineering Accreditation Criteria 2000. This criterion also includes requirements related to teamwork, communication, and design.

Numerous engineering programs have modified their curriculum to change the process by which design, teamwork, and communication have been taught. These changes include introduction of design in freshman level courses as well as in senior capstone courses. Specific methods used to teach the design process, such as reverse engineering and redesign techniques, are incorporated to improve the skills of engineering graduates. Schools have entered into partnerships with industry and the community to provide students with practical design projects and experiences. Engineering programs have also incorporated more emphasis on communication within the discipline and in design courses. The design review has also been incorporated into the design process in some programs and courses. Many of these papers discuss the presentation aspects of the design reviews. One paper cites conducting three critical design reviews with representatives from the sponsoring industry.

LSSU senior design courses have incorporated multistage design reviews in an interactive semiformal meeting with the customer. These design reviews move away from the presentation style format. The faculty that teach design at LSSU strongly believe that effective teaching and practice of design skills requires students to be involved in multistage design reviews. Further, these design reviews need to be “working” meetings where the students provide technical information to a customer in a setting that promotes two-way communication. Student assessment and feedback for this process have been gathered from the students. Data from graduates that have been in the field for three years will be available in the 2004 surveys of graduates from 2001.

Many industries utilize a structured design process that includes design reviews. These design reviews cover the phases of the design process from inception to production. For example, Siemens Automotive uses a nine-step design review process. Upper management reviews new products and processes early in the product inception phases. Design engineers and managers perform design reviews during product inception and development. Later in the process, manufacturing and quality engineers use design reviews to discuss and finalize production processes and to assure quality control. After each design review the project is evaluated and a color is assigned to indicate project status. Green indicates an acceptable status with no major concerns. Yellow indicates that concerns exist, but the project may continue. A yellow status requires project members to investigate the concerns and report back to management. Finally, red indicates major problems exist with the project and associated design. Work is halted until the major issues have been addressed. This entire process, which is used by Siemens, ensures that a quality product is produced and that lessons learned during the product development process are folded into future designs.

Similarly Continental Teves has a Technical Design Review Procedure, which is part of the TS-16949 quality documentation and compliance process. A design engineer is required to set a meeting time and place, invite representatives from appropriate departments, and create an agenda that covers the appropriate areas related to the design. Topics presented at the meeting include meeting objective(s), customer requirements, cost figures, drawings, FEA-reports, engineering changes, test reports, and an open issues list. The design engineer is also responsible for appointing someone to take and distribute minutes of the meeting. The minutes will contain
a list of attendees, the objective(s) of the review, a summary of the discussion, and the conclusion(s). The minutes become an official project and quality record.

The engineering and engineering technology programs at LSSU have incorporated design into their shared senior capstone project course sequence in order to bolster both the design and communication content of their curricula. The following sections of this paper discuss: the Background information regarding LSSU; the Design Review Process including the philosophy, purpose, fit in the overall communication process, and the details regarding the current process; the Benefits to the students and customer; and the Assessment Results to date.

Background
Lake Superior State University is located in the United States and is within sight of the Canadian border. The School of Engineering and Technology awards Bachelor of Science degrees in computer, electrical, and mechanical engineering as well as in manufacturing engineering technology. All of the programs provide the students with the opportunity to pursue an option in Robotics and Automation.

All engineering and engineering technology students are placed on multidisciplinary teams that complete a two-semester capstone design project. The majority of the projects originate with a proposal that is submitted to LSSU from industry. Projects cover a wide range of outcomes that go from performing research to designing and manufacturing of equipment or prototypes. Typical budgets for the projects are $15,000 to $25,000. Some of the past projects are listed below:

- Designing and building of a machine, located at the end of the production line, that tests the operation of automotive parking brakes;
- Designing and building of a machine, located at the end of the production line, that tests the operation of automotive column shift levers;
- Developing a prototype system to detect the characteristics of adhesive that has been applied to automotive glass in an automobile assembly plant;
- Developing, designing, and building of a device that accurately measures brake pedal travel while testing of antilock brake and stability control systems;
- Developing, designing, and building of a machine that calibrates automotive accelerometers that are used for testing of antilock brake and stability control systems;
- Developing and building a prototype system to show the feasibility of assembling numerous types of automotive tie-rod ends with robots;
- Designing and building of a low cost remotely-powered underwater vehicle that will be used as a research platform;
- Developing and building a system that causes misfires in an automotive engine and records the results.

Abstracts for this years and previous years’ projects can be found on the web at: http://engineering.lssu.edu/Students/seniors.html

The senior design courses at Lake Superior State University are taught and managed by a multidisciplinary board of engineering faculty called the Senior Projects Faculty Board (SPFB). Members of this board are responsible for all aspects of the course and set the standards for the design review process and participate in the reviews. Most of these faculty members also serve as mentors for a team of students. These individuals plus the industrial customers provide process and technical input to the students. In addition, the projects can afford faculty the
opportunity to engage in consulting with industry. Figure 1 shows a block diagram of the senior design experience at LSSU.

The Senior Projects Faculty Board selects the projects from the submitted proposals and assigns the students to a team. Each team is multidisciplinary and typically has a mix of computer, electrical, mechanical, and manufacturing students. The team creates a name and logo for its fictitious company. Each team is given an office space similar to one found in industry.

**Major Components of Senior Design Courses at LSSU**

![Flow Diagram of Senior Design Experience](image)

**Figure 1: Flow Diagram of Senior Design Experience**
The overriding philosophy used for these courses is a focus on preparing the students for work in industry. The course is seen as a transition from academia to engineering practice. Emphasis is placed on completing all course activities at an acceptable level instead of obtaining an acceptable grade. A strong emphasis is placed on communication, project management, and interpersonal skills in these capstone design courses. Communication topics and assignments cover a wide range that includes a formal proposal, a final report, formal business letters, business memos, peer evaluations, formal presentations, weekly business meetings, and design reviews. The projects require extensive interaction with the customer and the design review process represents one of the most significant aspects of this interaction. The students see that their project satisfies a customer need as it is accepted and implemented by an industrial company. Similarly, the industrial company can see how students work in a team with the idea of hiring students who have a proven level of achievement in the design review process. The current design review process incorporates the learning that has occurred over numerous years of experience.

**Design Review Process**

The design review is a key element in delivering a quality product for the customer. This structured event provides the mechanism to determine if the design meets the customer specifications and requirements. It also provides a medium for communication between the customer and the student team. The customer and experts in the field provide input regarding the quality, cost, and manufacturability of the design presented by the students. Communication in the design review is a two-way process between the students and the customers/experts. In the communication spectrum of formal reports and presentations to informal memos and meetings, the design review is in the middle. It is a semiformal event that is centered on the exchange of technical information. At LSSU it is viewed as a discussion of technical design and analysis in contrast to a presentation. Finally, the focus of the design review is to reach key conclusions and decisions upon which the customer and the student team mutually agree. It is common for the team to have action items or tasks that are the result of the review. Figure 2 shows a block diagram of the design review process.

Students are given instructions on the philosophy and mechanics of conducting design reviews. It is emphasized that the review is a semiformal meeting with a carefully planned agenda. A key aspect of the agenda is a list of the specific outcomes and decisions that are expected as a result of the review. Student teams are instructed to select a meeting facilitator, individuals to discuss and present each topic/design, and individuals to take notes and provide summaries at key points in the review. In addition to providing a lecture on the design review meeting process, sample “mock” design reviews are given to the students. Faculty members play the roles of team members for fictitious projects that are used throughout the entire senior design sequence.

As stated previously, a design review requires communication to flow both ways between the designers and the customers. For this to occur, the student team must provide the design review participants with a technical information package prior to the review. The package includes a cover letter, an agenda, a statement of the expected outcomes and decisions that will be determined, and the technical information that will be discussed and presented at the review. This gives the customers and engineering experts time to analyze the proposed information and designs and to communicate with other constituents that will be impacted by the proposed design. The students must demonstrate that they have done their homework relative to the designs and analyses. They need to be prepared to field questions and defend their designs,
LSSU Design Review Process

Input From Customer & Faculty

Senior Projects Design Reviews

Third Design Review: Testing & Acceptance Criteria

Optional Design Review

Second Design Review: Hardware or Software

Optional Design Review

First Design Review: Hardware, Software, or Investigation Findings

Instructions On Design Review Process & Mock Design Review

Senior Projects Faculty Board

Status: Green Yellow Red

Figure 2: Flow Diagram of Design Reviews
while still being willing to listen to the customer’s input. The last point is a fine line that students often have difficulty accomplishing.

As previously stated, faculty conduct two example design reviews. These help the students better understand the design review process. The first review covers a design-and-build style project while the second covers a research project. Faculty members play the roles of facilitator, presenters, minute taker, and customer. Emphasis is placed on the product specifications and decision process. The customer plays the typical role asking all types of questions that the team may and may not have anticipated. The meeting facilitator demonstrates meeting control. Summaries are provided at key junctures in the process.

The students are required to complete at least three design reviews. In previous years, a single review was used, however this was inadequate for providing a quality product and giving the students adequate practice in conducting a design review. The SPFB settled on incorporating three design reviews. In addition, a multistage process was initiated to better match the processes similar to those cited in the background section. Specifically, in the first two reviews, the student teams must present technical designs and/or technical research results. These reviews are directed toward design and selection of system components. In the third review the students must present their technical test plans that will be used as they build and test their product or prototype.

The outcome of the design review will be decisions that set the direction of the project and a status for the team. The decisions made will be firm and must be reevaluated by all parties before any changes can be made. Upon completion of the design review, the status for the team will be red, yellow, or green.

Red status means that the team’s design review and possibly the design has serious problems. Key information is missing or serious errors were made in the design/decision process. If a team receives this status they are to put the current design on hold and complete the required tasks that will provide them with the needed information to continue with their project. A red status typically reflects negatively in the students’ grade. However, there can be situations where the customer has changed the direction of the project due to external factors and technical information presented at the review, and thus a red status is the outcome. This does not reflect negatively on the team’s grade.

Yellow status means that the design review and design was basically acceptable, but some key items must be completed before the decisions from the review are finalized. This is the typical outcome for a successful review where quality interaction has occurred between the team and customer. Students are given a business memo that specifically identifies the required tasks and the person(s) that have approval authority. Once all follow-up items are completed, the team’s status returns to green. A yellow status does not reflect negatively on the grade for the design review.

Green status means that all aspects of their design review were acceptable and no follow-up items are required. This status is rare.
Benefits to Students
An ability to communicate is listed as the most important skill for experienced engineers and the second most important skill for entry level engineers in the PRP. Students at LSSU expand and practice this skill while dealing with industrial customers and technical experts in the design review process. As their project progresses through the two semesters, the students transition from the “student engineer” to the expert for their design and product.

The three design reviews enable the students to develop their communication skills at multiple levels. The design reviews require the students to write formal documents and technical descriptions. In the reviews the students develop skills to verbally explain their designs. They also apply CAD skills that were learned in previous courses to explain and demonstrate their ideas. A key point to this communication experience is that it occurs in the semiformal setting that is common to many engineering situations. Engineers must have the ability to give a formal presentation, however this is not the most common scenario found in their daily activities. It is critical that engineers can explain their concepts and designs to an engineering and management audience. They must also be able to answer questions regarding their concepts and designs for these same audiences. Students learn to prepare for a technical review and anticipate questions. They must also learn the delicate skill of defending their ideas while listening to customer input. Ultimately they learn that through communication of the “greater team” the best concepts and designs are produced. Finally, the students learn to facilitate and control the meeting flow. Often it can be a challenge to keep the review on track to assure that the desired outcomes are achieved.

As part of the design review process, student teams frequently must prepare more than one solution to their project. The team must present advantages and disadvantages to each potential solution, as well as a team recommendation for a solution. The design review process is where the student begins to learn the decision making process in applying his or her core engineering skills.

When the students start their projects they typically see the faculty and customer as all-knowing regarding the technical aspects of the project. They expect the faculty and customer to have all of the answers. Faculty mentors guide the team and enable the students to realize that the customer often does not know all of the specifics of what they want. At the onset of the project this is a very difficult concept for students to understand. As the project progresses, and particularly through the design reviews, the students become the experts and the ones with the most knowledge regarding the technical aspects of their designs. This prepares the students for their future engineering positions and interface with management.

Assessment Results
LSSU started a comprehensive assessment process in 1998. Currently each course has stated learning objectives, some of which are directly related to design and communication. Student performance and perception is measured relative to these objectives. For the two capstone courses, the specific learning objectives related to communication and design are listed below. A specific question that is asked regarding confidence in design is also listed.

1. The students will be capable of giving an effective, professional, oral presentation and design review.
2. The students will demonstrate effective writing of short, professional memos and letters.
3. The students will be capable of using creative problem-solving techniques for solving business and technical problems.
4. What is your confidence level in approaching a design problem?

At the completion of each semester, faculty members conduct an assessment session to gather data and feedback from the students. The bar graphs of figures 3-6 show the average student team grade and the students’ perception (based on a 100% scale) of their performance relative to the above objectives and question. For the data shown the average sample size was 40 students per year. As can be seen by the data, the percent difference between the student performance and student perception varies from 1% to 5%.

Performance for Objective 1: The students will be capable of giving an effective, professional, oral presentation and design review.

Figure 3: Student Grade vs. Perception for Objective 1

Performance for Objective 2: The students will demonstrate effective writing of short, professional memos and letters.

Figure 4: Student Grade vs. Perception for Objective 2
Performance for Objective 3: The students will be capable of using creative problem-solving techniques for solving business and technical problems.

Sample student comments related to the design process are also provided below.

- Class provides plenty of opportunities to prepare and give presentations, design reviews, etc.
There were many examples given to us on how to write a memo. There are also a lot of assignments that require memo writing.

In doing our project we are required to solve many problems. With being exposed to a real business you get a taste of real problems that come up.

By gaining the experience in senior projects, it has given me added confidence in approaching design projects.

I think I am more capable now, because I have learned to listen to other people's opinions and ideas. I also feel like I usually have many good design ideas.

This is a real design project and we are learning the skills in approaching a design project.

Yes, I have always loved designing and after this class I know how to go about it in a professional manner.

I feel reasonably confident. This class gives us our opportunity to get real-life design experience. Now we won't be walking in blind when we start work.

The planning, proposing, design, implementation and presentation skills were well taught and simple to apply.

Yes, this class gives us experience and tools to use on an engineering design project, example project and design reviews help

Yes, through the design, build, test planning, I feel more confident in approaching design projects.

I feel that senior projects has given me a chance to understand what may be involved in actual design projects on the job.

With the learning experience in this class, when approaching design projects I am definitely more confident now that the correct steps necessary have been learned and used.

Yes, I feel that the work has prepared me to understand what will be faced in an industrial setting.

Yes, I feel confident in my design review experience, however, both manufacturing and EE's are unfamiliar with this common procedure and I think teams would benefit more with this experience, also Pugh analysis.

Our project was very much design oriented. We learned to weigh the pros and cons of several solutions to best meet the customer’s need.

Conclusion
The process of conducting design reviews in the capstone design courses at LSSU has evolved and improved over the past four years. Students are required to conduct at least three design reviews for their project. The main purpose of the design review is to improve the quality of the design through feedback from the customer and other technical experts. The first two reviews focus on the technical aspects of the design and the third emphasizes the testing of the product. This review process is patterned after the approach used by many engineers within industry. In these design reviews the students interact with a customer in a structured semiformal setting. They develop and refine written and oral communication skills related to the technical aspects of their designs. More specifically they learn how to: facilitate the design review, handle technical questions, use customer feedback, and how to make decisions using their engineering skills. Assessment data indicates that the learning process is effective and valued. Ultimately the quality of the graduates and the capstone design product is improved through these design reviews.
Bibliography


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