Product Dissection: An Important Tool for a First Year Introduction to Engineering Course Project

A. Hande, W. He, N. Barakat, M. Carroll

Lake Superior State University
School of Engineering and Technology
Sault Ste. Marie, MI 49783

Abstract

Product dissection and benchmarking are processes commonly employed in industry to improve product design, produce superior performance, and product quality. The process, when applied in an undergraduate academic setting, can improve the process of teaching engineering design. It has been applied to teach an undergraduate freshman Introduction to Engineering course. The course focused on product dissection methods, encouraged student participation in the form of teams, and provided students with invaluable presentation and technical writing experience as well. The students were encouraged to engage in a market study of toy cars/trucks with defined specifications, and select an appropriate sample product to carry out a benchmarking study by dissecting the unit. Each student group next conducted a comprehensive Pugh analysis to compare the dissected product with their perceived design. The next step focused on conducting design reviews wherein students presented their ideas and were critiqued by faculty and senior year students. The course culminated with each group implementing their final design and demonstrating it during final's week.

Introduction

Traditional freshman year engineering curricula contains an Introduction to Engineering course that always possesses a vital project component that encompasses various fields of fundamental engineering to help students narrow down their field of specialization. This project contains important components such as basic research, creative design and development, and written and visual presentation of results to a professional audience.

Many students have trouble with these design projects partly because they are being exposed for the first time to methods and requirements for which some maintain they should have been prepared earlier. In order to provide these students the necessary ingredients for successful project completion, it is quite important to make use of innovative product development techniques. One such tool called *Product Dissection* can be used to provide information on actual project components, fabrication, cost, and aesthetics by disassembling and re-assembling a variety of everyday items including bicycles, drills, telephones, and single-use cameras, to teach students the fundamentals of a good design[1,2]. This tool has been used by freshman year students during their project implementation in the Introduction to Engineering (EG101) course at Lake Superior State University (LSSU) during Fall 2004.

This paper describes the Fall 2004 EG101 course project wherein students designed a prototype four-wheel battery powered toy car/truck using *Product Dissection* methods. The general and specific criteria used for evaluating available products that matched the project specifications and eventual component selection for lowering cost has also been described. Each team was encouraged to dissect toy cars and trucks that were readily available in the market that matched project specifications, and compare these products based on functionality, commonality of components and materials, assemblability, etc. These results were documented by each team and a Pugh analysis was performed in order to weigh the advantages and disadvantages of each available device. The chosen design was next presented to faculty and senior year students in the form of a comprehensive project proposal to obtain their suggestions to improve the design. After design approval, the necessary components were purchased and the device was fabricated by each team. Finally, each fabricated design was comprehensively tested and compared with available products in the market with respect to cost, size, weight, appearance, ease of assembly/disassembly, and reliability.

The Design Process and Product Dissection

Product dissection and benchmarking are processes commonly employed in industry to improve product design, produce superior performance, and product quality. The process, when applied in an undergraduate academic setting, can improve the process of teaching engineering design. As noted earlier, this concept has been applied to teach undergraduate freshmen engineering students at LSSU. The students, working in teams, conducted a market study of toy cars/trucks based on certain defined specifications and carried out the benchmarking study by dissecting each unit.

The design process is the procedure whereby the designer, starting with customer or market expectations, develops a product or a process to meet a specific demand. To describe this process, current textbooks focus primarily on the creation of design concepts[3], the development and analysis of detailed designs[4], material selection, and somewhat less rigorously, on the manufacturing and testing of the finished product. Figure 1 shows one such design process model which contains all the basic design steps, but omits the manufacture and testing of the final finished product. Such a model is ideal for depicting the design process to undergraduate students (especially freshman) because generally this strategy provides adequate time to not only lecture the material satisfactorily but also to implement an acceptable prototype that warrants manufacture.

The practical, but equally important issues of product specification and analysis of critical design features are still alien to the students. In dissecting any given product the device operation is examined, the relationship between the parts and components is studied, and the functional and operational requirements of the product are noted. Critical design features and the detailed implementation of the design concept to meet the product specifications can be observed and cataloged. Furthermore, the manufacturing and assembly processes employed can be inferred. Therefore, current textbooks can be complimented using such a technique.

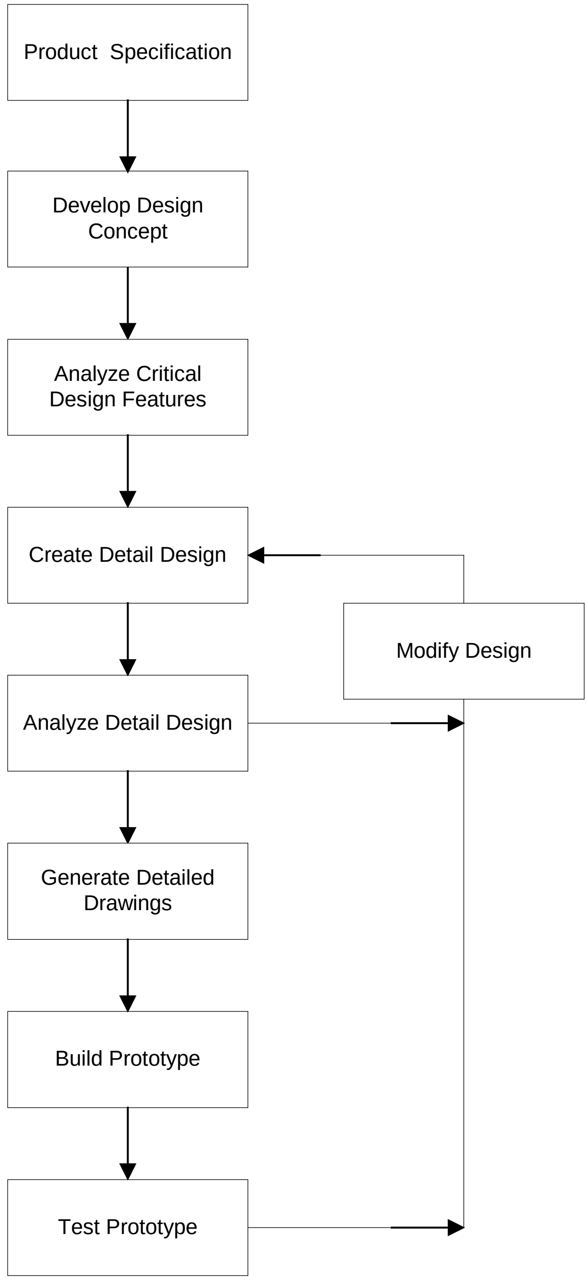

Figure 1. A typical design process model

The Benchmarking Process

In industry, benchmarking is an accepted technique used to identify the strengths and weaknesses of a wide range of processes, procedures, and operations associated with the company business. Areas of concern ranges from customer satisfaction, product design and manufacturing, and business operations such as order entry, billing, or repair services. Benchmarking[5] typically searches for the best practices, thus leading to superior performance. The typical steps in the process are shown in figure 2.

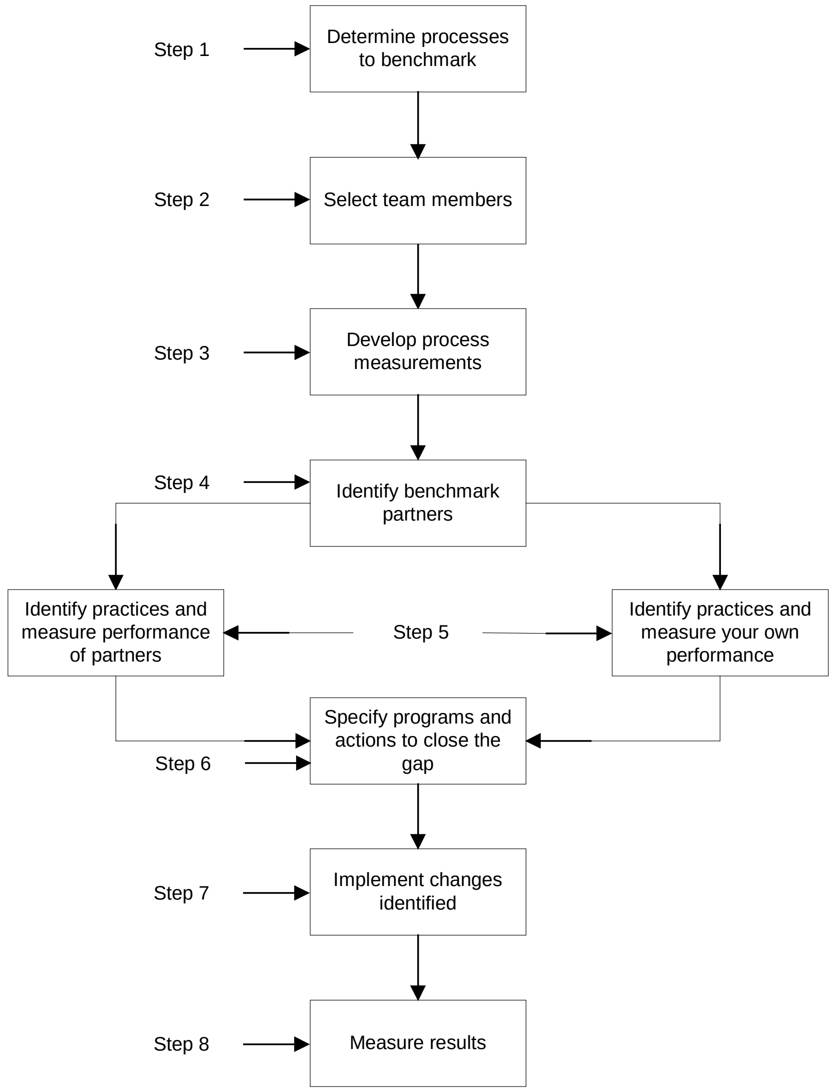

Figure 2. A typical benchmarking process model

In order to emulate the product design process, students were placed in teams. The students examined, tested, and re-designed an industrial product (toy car/truck) to meet market demand for product superiority. This technique provided a natural setting for implementation of the design process that they will experience in industry after graduation. Working on a real product allows the student team to discover and confront issues that the original product designers had to face, thus instilling knowledge and experience not provided through textbooks.

Benchmarking a Toy Car/Truck

The EG101 course project focused on using the basic design and benchmarking processes as tools to steer students towards their goal of implementing their specific project in a more efficient manner. The individual steps used by the students are depicted below:

Step #1 Determine the Product: A Ford F-150 toy truck was selected as the product during the benchmarking and dissecting exercises. Figure 3 shows the toy that was dissected. This dissection exercise familiarized the students with the components (such as motors, batteries, wires, and outer frame) that they would require for their respective designs. The students were allowed to use the procedure shown in figure 2 for their design and were familiarized with the basic product components needed to implement such a toy. The customer specifications given to the students were as follows:
1. Maximum voltage rating of motors = 9 VDC.
2. Maximum wheel diameter = 3".
3. Maximum size of the toy (WxLxH) = 8"x12"x 4".
4. Absolute minimum features must include forward and reverse motion.

Figure 3. The Ford F-150 toy used for the dissection exercise

Step #2 Team Selection: The course instructors selected the members for each team based on individual student interests, skills, and their performance in the course. The objective was to establish a set of equally competent teams. Eight teams were formed, with six-eight students per team.

Step #3 Develop Process Measurements: The students were provided with a copy of the basic specifications (as listed in step #1) as an example of customer expectations and design features that are deemed appropriate to verify product performance. Each team was requested to contemplate, act on, or study the following:

1. Generate a list (as many as you can think of) of features and functions that could possibly be important to the total success of the toy car/truck.
2. What factors most account for customer satisfaction ?
3. What are the major costs (or cost drivers) of the device ?
4. Which functions in the device represent the highest fraction of the cost ?
5. Which functions have the greatest room for improvement ?
6. Which functions have the greatest effect or potential effect for differentiating the Ford F-150 toy from other toys ?
7. What five factors do you believe will have the greatest impact on the success of your toy in the marketplace ?
8. How could the five factors be evaluated ? What metrics could we use ?

9. Identify as many real toy cars/trucks that satisfy the basic specifications in the market. Evaluate them using Pugh analysis (i.e. evaluate them without disassembly).
10. Which toys appear to be leaders in each of the factors or features ?

Step #4 Identify Benchmark Partners: Student teams conducted a market survey, from the least expensive to the most expensive models, based on item 4 in step #3 above.

Step #5 Identify Practices and Measure Performance: The student teams performed a detailed Pugh analysis as indicated on item 9 in step #3 above. The teams made careful records in their design journals on all features, uniqueness of design, manufacturing or other aspects that they observed during the dissection exercise of the Ford F-150 toy truck or any toy of their choice readily available in the market. Each team prepared a summary report on the dissected unit. The summaries were used to obtain information regarding device components as well as to make a comparative analysis of the available market device and their perceived design. The students were encouraged to save cost and add extra features to their design to make it more competitive. The Pugh analysis played an important role in their decision making. One such analysis is shown in Table 1 where Team "Etch-A-Sketch" analyzed their design with two "Ready to Go" toys available in the market.

Table 1. A typical Pugh analysis

Criteria	Radio Control 'Ready to Go' Car	Manual Control 'Ready to Go' Car	Our – Radio Control Car
Price	0	+1	+1
Speed	0	-1	+1
Weight	0	+1	0
Dimension	0	+1	+1
Communication	0	-1	0
Convenience	0	-1	+1
Lights	0	-1	+1
Visual Indicators	0	-1	+1
Show	0	+1	+1
Forward/Reverse Drive	0	0	0
Right/Left Turn	0	0	0
Maintenance	0	-1	0
TOTAL	0	-2	+7

Step #6 Programs and Actions to Close the Gap: This was a critical step in the exercise. The teams had to identify the changes that needed to be implemented in their design to achieve their objective of reduced cost and added features. This step involved detailed pricing of components and comparing the total cost with the cost of the dissected device. The preliminary designs were drawn on paper and a professional presentation was conducted wherein each team presented their preliminary design in the form of a design review.

Step #7 Implement Changes Identified: After approval of the designs, each team was now requested to proceed towards procuring the necessary components and begin their project implementation. Because of time constraints the instructors were also involved in helping the students to effectively purchase their components and fabricate the design.

Step #8 Measure Results: After implementation of their respective designs, each student team measured the performance of their device during "Testing Day". The intended design features and productivity were compared to their original estimation. Compromises were noted and a final report was compiled. Each student team was required to demonstrate their device to their instructors for final evaluation.

EG101-Introduction to Engineering Project Outline

The project-related objectives of the EG101 course was to provide the students with adequate technical and professional experience during the implementation of their project. This was necessary because basic skills such as teamwork, leadership, presentation skills, and technical report writing are lacking in engineering freshman. Moreover, all graduates of LSSU's engineering programs complete a capstone senior year experience[6-8]. This experience consists of either an industrial senior project or a faculty-directed research project. The engineering four-year curriculum at LSSU is structured to support these senior projects by embedding design reviews and project presentations/report writing exercises within courses. The focus was to expose freshmen to these vital components and improve their skills before entering their sophomore year.

The specific EG101 project-related objectives are listed below.

1. Describe clearly the steps involved in designing a product or a solution to an engineering problem and the additional steps involved in implementing the design.
2. Function effectively on a design team with fellow students in such a way that the ideas and capabilities of the individual team members are combined in an optimum manner.
3. Write a detailed set of engineering specifications for a product or a solution based on input data from a prospective client.
4. Systematically evaluate design alternatives as they relate to these engineering specifications, also taking into consideration factors such as product safety, social and environmental, responsibility, and the availability of necessary resources.
5. Procure the materials and equipment necessary to implement the proposed design or solution, by using, information from business registers, trade journals and catalogs, and electronic sources.
6. Prepare a technical proposal recommending a given design or course of action to a prospective client and orally and visually present this proposal.
7. Construct a device based on the selected design and perform on this device preliminary testing, both for normal and off-design conditions, and final testing in the presence of the client.
8. Prepare a final technical report in a standard engineering format, describing fully all aspects of the project, including device design and implementation, testing results, and principles of device operation.

The project duration was to be about fourteen weeks, commencing during the first week of classes, and ending with "Evaluation Day", when each design group was to subject their device to final testing and evaluation.

Figure 4 shows the progression of activities in the project and the weeks in which these activities were performed.

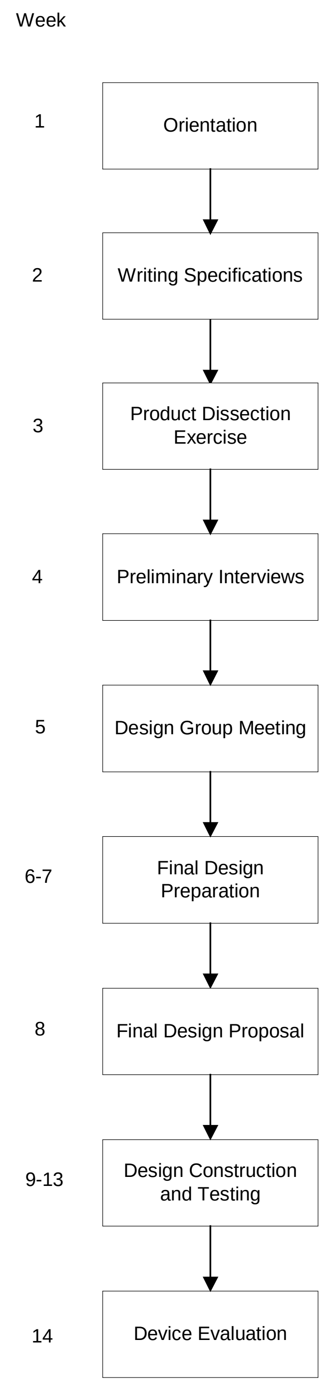

Figure 4. The EG101 course project schedule

Scheduling was based on a fourteen-week semester, with a single 120-minute laboratory period allocated for each week of classes. A general orientation was given during the first laboratory period, and during Week 2 the students were given a letter from an imaginary toy manufacturing company. Using the absolute minimum specifications given in the letter, the students were instructed to construct their toy car/truck. The device required a combination of mechanical and electrical skills. During an in-class exercise, the students developed a set of engineering specifications for this toy. These included general, qualitative, and quantitative specifications as well as device limitations and additional characteristics such as cost. They were then allowed to discuss these specifications with other students and modify them appropriately, before submitting them the following week.

Week 3 focused on dissecting the Ford F-150 toy to obtain information about potential components and basic design features. The students were then provided adequate time to develop a preliminary design concept for the toy. A brief description of the design concept with an accompanying sketch was to be submitted by Week 4, during which interviews were to be conducted with each individual student.

During the Week 4 interviews, each student presented his or her design concept to the instructor, and based on these interviews students were assigned to design groups. The instructors attempted to group students according to the general device type envisioned. For example, students proposing a wireless radio controlled toy design were grouped together, as were those interested in implementing a tethered controlling mechanism.

Design groups met for the first time during the Week 5 laboratory period, and each group was required to develop an organizational structure. This structure had to include an overall leader and a treasurer, but there was considerable flexibility in the establishment of additional roles for group members. Each group was required to submit an "organizational report", which consisted of an organizational chart, a job title and description of duties for each student, and contact information such as telephone numbers or e-mail addresses.

Design groups then had three weeks to finalize a design and prepare a written design proposal for review by the imaginary toy manufacturing company. During the project, the instructors assumed the role of reviewers from the client company, and students were required to present their proposal as a group during a special session scheduled during Week 8. The oral presentation was to be accompanied by appropriate visual aids, and students were subjected to questioning by the prospective client. Figure 5 shows one such design review presentation for team "Ranchero Racers".

An orientation on procurement and subcontracting was given during Week 6 while the students were evaluating designs and preparing design proposals. This orientation included information on the use of business directories, trade journals and catalogs, the internet, and local publications.

Following the Week 8 design briefings, students had several weeks to build and test their toy car/truck. A "hands-on" orientation on experimental design and device testing was given during Week 11, using a device constructed by the instructors. The instructors provided students with basic machine shop and soldering experience during this week as well. Figure 6 shows one such exercise where students were provided basic machining skills in the machine shop.

Figure 5. Design review of team "Ranchero Racers"

Figure 6. Machine shop exercise for EG101 students

Results

Students zeroed in on the 'market appeal' aspects through novel ideas for 'good looking' and attractive units. The student groups made good use of technical resources for analyzing the Ford F-150 toy and proceeding towards their own designs. One group made extensive use of the internet for access to detailed design information. Team spirit grew with the use of the product dissection exercises and the subsequent team decision processes where they had to negotiate for a mutually satisfactory design. Report presentations, both written and oral were of high quality and employed prototypes, pictures from product literature, and hand drawn sketches.

Perhaps the most surprising aspect of the entire project was the ability of the students, many of whom had never engaged in a project of this nature, to construct devices that accurately performed their prescribed functions. All eight groups designed their prototypes with their own unique designs. Every design was different from the others. For example, some groups used DC motors for steering control while others used stepper motors. The outer frame design was drastically different as well. The gear ratios were unique for each design. Lack of originality certainly was not a problem. Figure 7 shows one such design for team "Etch-A-Sketch".

Figure 7. Final prototype design of team "Etch-A-Sketch"

Many students started with wildly imaginative design concepts, and at some point during the construction of the devices imagination collided with the engineering realities of material limitations and difficulties in device control. Yet these realities were not enough to limit the proliferation of designs, and it was certainly concluded that there is more than one way to build an engineering device to meet specifications. Learning the practical aspects of working as a team was one of the more rewarding aspects for many of the students. The project exposed the students to basic electric and mechanical skills in a fairly methodical manner.

Conclusions

The combination of product dissection and benchmarking process was found to be highly effective for teaching freshman students about product design at the conceptual, implementation, and detailed design stages. Students received basic training in both electrical and mechanical engineering areas as well, and exhibited remarkable capabilities in designing and building devices that performed according to specifications. The product dissection and benchmarking exercises helped immensely towards introducing students to engineering design and the production process. The tools exposed students to the necessary requirements of what processes and skills are used in the engineering profession. The project covered all eight steps of the benchmarking process. The students evaluated their design choices towards the end of the course and appreciated the methodical approach of the product dissection and benchmarking exercises.

Acknowledgments

The authors would like to express their gratitude for the support and encouragement they received from their colleagues in the School of Engineering and Technology at LSSU, and for the highly diverse, intelligent, and motivated group of freshmen students that made the implementation of this project such a rewarding experience.

Bibliography

1. J. S. Lamancusa, M. Torres, V. Kumar, J. Jorgensen, "Learning Engineering by Product Dissection", ASEE Conference Proceedings, June 23-26, 1996, Washington DC.
2. Jens E. Jorgensen, James Fridley, and John S. Lamancusa, "Product Dissection - A Tool for Benchmarking in the Process of Teaching Design", Frontiers in Education Conference Proceedings, Salt Lake city, UT, November, 1996.
3. George E. Deiter, "Engineering Design: A Materials and Processing Approach", McGraw Hill, 3rd Edition, 1999.
4. Nigel Cross, "Engineering Design Methods: Strategies for Product Design", John Wiley and Sons, 3rd Edition, 2000.
5. James Fridley, Jens Jorgensen, and John Lamancusa, "Benchmarking: A Process for Teaching Design", Frontiers in Education Conference Proceedings, Pittsburgh, PA, November 1997.
6. P. Schmaltz, K. Schmaltz, P. Duesing, and D. Goodrich, "A Capstone Senior Engineering Design Course: A Project Case Study and Its Subsequent History", ASEE Annual Conference Proceedings, 2001.

7. K. Schmaltz, P. Duesing, R. Anderson and Zoerner, "Lessons Learned from Teaching Industry-Based Senior Projects", ASEE Annual Conference Proceedings, 2001.
8. D. McDonald, J. Devaprasad, P. Duesing, A. Mahajan, M. Qatu, and M. Walworth, "Re Engineering the Senior Design Experience with Industry Sponsored Multi-Disciplinary Team Projects", Frontiers in Education Conference Proceedings, Salt Lake City, November 1996.

Biographical Information

ABHIMAN HANDE
Dr. Hande is an Assistant Professor in the ECE Department at Lake Superior State University. He received his B.E degree from the University of Bombay in 1996, and his M.S and Ph.D degrees from the University of Toledo in 2000 and 2002 respectively all in Electrical Engineering. His research interests are power electronics and real time embedded systems. He is presently working on improving performance and extending life of HEV battery packs.

WENDY HE
Dr. He is an Assistant Professor in the Mechanical Engineering Department at Lake Superior State University. She received her B.S degree from the National University of Defense Technology (China) in 1985, and her M.S and Ph.D degrees from the University of Maryland in 1993 and 2001 respectively all in Mechanical Engineering.

NAEL BARAKAT
Dr. Barakat is an Assistant Professor in the Mechanical Engineering Department at Lake Superior State University. He received his B.Eng degree from Kuwait University in 1989, his M.A.Sc degree from Concordia University in 1996, and his Ph.D degree in Mechanical Engineering from McMaster University in 2000. His primary interests are mechatronics and engineering ethics.

MATTHEW CARROLL
Dr. Carroll is an Assistant Professor in the Mechanical Engineering Department at Lake Superior State University. He received his M.S and Ph.D degrees from the University of Illinois in 1982 and 1986 respectively. His interests focus on a variety of mechanical engineering and mathematics topics.