SB^{3}C2015
Summer Biomechanics, Bioengineering and Biotransport Conference
June 17-20, 2015,Snowbird Resort, Utah, USA

TEACHING UNDERGRADUATE DESIGN: AN APPROACH BASED ON INDUSTRIAL EXPERIENCE

Martin L. Tanaka

Department of Engineering and Technology
Western Carolina University
Cullowhee, NC, USA

INTRODUCTION

The design of products is an important area in bioengineering and the field of engineering in general. In fact, it is this desire to create something new that attracts many people to pursue careers as engineers. Using the foundational skills learned in the classroom, adding specialized knowledge gained during employment, and some creativity, amazing new products have been developed that have changed the world. The purpose of this abstract is to share the basic principles of engineering design and show how these can be effectively taught to undergraduate students.

The author has over 11 year of experience as a design engineer working for several different companies including Texas Instrument, Siemens VDO, and ABB. Products designed include pressure switches for control of air conditioning and refrigeration systems, an automotive cruise control unit for Saturn, an instrument Cluster for Mercedes Benz, a clock and outside temperature module for Volkswagen, and a mass spectrometer for ABB. Experience was gained working as a junior engineer, senior engineer, project manager, mechanical engineering supervisor, and engineering manager.

METHODS

The design of an engineered product is both similar to and different from non-engineering design. Both approaches require an understanding of the problem, creativity, and processing skills to transform raw materials into a completed product. However, engineering design also utilizes engineering calculations to predict the performance of a new design prior to building and testing the product. An examples of these types of calculations are to determine the size of the motor, pump, and pipes needed to transport water from one reservoir to another for an artificial waterfall. The pressure head, volumetric flow rate, and flow resistance can be taken into account prior to purchasing the motor, pump, and piping. The initial conceptual design can be modified (scaled) appropriately so that the finished product has a good chance of operating correctly the first time. An alternative to the engineering approach is to arbitrarily pick the motor, pump, and pipes without the benefit of calculations. After the system is built it can be tested. If the “guess” was correct, the system will function properly. If not, new components must be purchased, the design rebuilt, and the system tested again. This “trial and error” approach is undesirable for several reasons. Equipment may need to be purchased multiple times increasing the material cost of the project. In addition, each trail requires labor to rebuild and retest the system. To overcome these problems designer will tend to choose larger and more expensive components, but this leads to overdesign and wastes money. In addition to the increased cost, ordering new parts, rebuilding, and retesting all take time. This increases the time needed to complete the project. In this simple example it is clear that taking some time to perform calculations can dramatically improve project success.

In other cases, there are multiple variables that affect product performance and achieving a small window of parameter values is required to produce a functional product. An example of this is the design of an aircraft. It is not feasible to simply increase the thickness of components to overcome stress failures because this also adds weight. Creative solutions, calculations, advanced materials and computer simulations are critical to reducing product development time and cost.

Although these principles seem rather simple and logical, engineering students (and even working engineers) often use the “trial and error” approach. Inexperienced engineers generally have the skills necessary to perform the calculations, but lack practical experience having only performed these calculations in the classroom environment. This is readily apparent in senior design courses where student generally want to purchase components of a system that were selected arbitrarily. By helping the team to perform an often simple calculation, the proper components can be specified saving both time and money.

RESULTS

Below are other product design principles, tips, and best practices that may be helpful when conducting and/or teaching engineering product design.

Overview of the Entire Product Design Process

- Understand the product that you are trying to design including customer specifications, competitive products already in the market, government or regulatory constraints, etc.
- Develop a conceptual design (or several). Be creative and take the best aspects of all the designs and combine them. Evaluate the pros and cons. Consider the risks in each approach. Select to a single design concept to take to the next phase.
- Create a detailed design. A detailed design includes all the information that can be put "on paper" without actually building a prototype. It includes calculations and specification of all components. In theory, the design engineer should be able to hand the document to someone else and they could build the prototype without personal involvement.
- Build a prototype and test it to verify the design. Optimize the design, rebuild, and retest.
- Build production tooling and create the manufacturing line.
- Build parts on the line and test again to validate the design before going into full scale production.

Mentoring Students and Managing your Design Team

- Select a team leader to coordinate activities of the team & write meeting minutes (not the faculty member).
- For senior design projects, your product is a design (CAD drawings, electrical schematics, board layouts, test results, etc.). The physical prototype is only part of it.
- Teach critical thinking. In our fast paced world it is easy to just glance over information and only respond to something that "jumps out" at us. This is not a good approach in engineering design. It is better to think about your design, all possible outcomes and worry a little.
- Teach students that the reason products often fail is due to an unanticipated mode not taken into account in the design.
- Spend time with your students. Seeing how you approach a problem and how you interact with a customer will help them greatly. Be a good role model.
- Initially you should show the students what to do and have them follow your lead. As they gain experience, begin shift the responsibility to the students. Let them lead. You should follow, support, and provide guidance.

Manage the Scope of the Project

- Be realistic about what can be accomplished in each phase of development.
  - Sr. Designs: part time work by inexperienced people over ½ - 1 year → proof of concept prototype
  - Graduate Student: dedicated effort by an inexperienced person → working prototype
  - Faculty: Part time work → results will vary
- Be careful not to allow your student to do "Lego" designs for senior projects where they simply assemble existing products into a system. There needs to be a custom design component in order to teach them how to do this type of work.
- Break projects into phases, each with a defined and achievable scope (applies to all projects, not just student projects).
- Breaking the design into phases can be helpful to maintain focus on measureable and verifiable results.
- Select a project that is challenging, but not so much that it cannot be accomplished.
- Watch for scope creep by both the customer and the students.
- In contract engineering something extra can often be squeezed if not difficult for "good will". However, if the proposed change becomes involved, a contract amendment will be needed that can effect engineering design cost and piece price.

Business, Business Culture & Professionalism

- Design of engineered products is closely tied to business.
- Teach students how to communicate with a customer in a professional manner.
- Teach students to set achievable goals for yourself and achieve them. It is better to negotiate the scope of work or the deadline than to accept more than can be accomplished, miss the deadline, and let down the team.
- Use meeting minutes to track each assignment and due date.
- Teach students the basics of intellectual property (patents) – Inventor, Assignee, Costs of a Patent, Quality is important (loop holes), Types Utility vs. Design.
- Cost is always an important factor to consider in the design of commercial products.
- Basic knowledge of economics is important including return on investment, amortization of fixed costs (engineering, tools and equipment), design cost estimations, product cost estimation (costed Bill of Materials), development timeline estimation.
- It is exciting to watch people grow from naïve students into professional colleagues able to handle themselves in the business world. This applies to senior design students, graduate students, and junior engineers.

DISCUSSION

The above list is only a small portion of the entire body on knowledge available on product design and the teaching of this subject. It highlights some important basic ideas and acts as a guide for using engineering in product design. It includes lessons learned, warns of possible pitfalls, and presents best practices to train student for entry into the work world. It is a pleasure to teach practical product design principles to students and colleagues. I encourage people who are interested in product design to contact me or others with industrial experience before beginning your next engineering design project.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the faculty an NCSU and Virginia Tech who taught me the principles of engineering. Furthermore, I would like to thank my colleagues at Texas Instruments and VDO for helping me to learn the necessary skills of engineering practice. Finally, I would like to express my sincere gratitude to Werner Eckardt for being an excellent role model, mentor, and friend to me during the early years of my career.