# Engineering Design Process –An Interdisciplinary Approach

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*Abstract* - **In the 21st century, modern engineering design is practiced as an interdisciplinary endeavor requiring individual engineers to work as part of a team that involves a range of specialists. An interdisciplinary approach to engineering design sensitizes team members (students, faculty and industry partners) to multiple perspectives and discourages them from taking comfort in the singular domain to which they are accustomed. Students in Functional Apparel Design and Thermodynamics & Heat Transfer were to design a garment for the human torso that will facilitate heat transfer considering a particular environment, activity, or both. These research activities engage interdisciplinary student teams in collaborative research with industry and help promote teaching and learning while utilizing methodologies focused on solving functional design issues using an innovative application of industry-relevant technology. The result is a well-prepared professional who can balance technical training with a firm understanding of scientific inquiry and industry practice. This paper provides a framework for creating models of successful interdisciplinary collaborative projects between university and industry.**

*Index Terms* – Design process, Engineering Education, Interdisciplinary, Student teams,

## I. INTRODUCTION

In the 21st century, modern corporate design, often referred to as concurrent engineering, is practiced as a multidisciplinary endeavor requiring individual engineers to work as part of a team that involves a range of specialists [1]-[3]. Technological evolution, changing corporate structures and global competition require increased emphasis on problem solving, creativity, and interdisciplinary collaboration [4]. Additionally, new technologies perpetuate a range of design possibilities, creating what Parsons and Campbell [5] refer to as a “complex and multifaceted set of decision points” for engineers, researchers, technicians and product developers. Preparing future professionals for this dynamic environment is both a challenge and an opportunity for academic institutions. The intersection of diverse fields such as apparel design and engineering encourages the sharing of problem solving strategies, research methodologies and an appreciation of backgrounds different from ones own. When candidate engineers and apparel designers converge on a common problem presented to them in the college classroom, they are confronted with the reality of operating as team, just as is done in the "real world". A multidisciplinary approach to problem solving sensitizes team members to multiple perspectives and discourages them from taking comfort in the singular domain to which they are accustomed [1]. Collaboration in the college classroom between functional apparel design students and engineering students offers the potential for creative design analysis that is beyond the scope of any one perspective or discipline.

According to Finiston *et at.* [6] in order to best prepare the future engineer, the structure of traditional electrical and mechanical engineering curriculum will need to change as industry demand will be for engineers who can utilize a team-based, multidisciplinary approach. While many individuals possess natural traits that can facilitate group dynamics (e.g. leadership, writing, speaking, personality, etc.), the ability to work in a team is a learned skill. Current Accreditation Board for Engineering and Technology [7] and National Association for Industrial Technology [8] accreditation standards stress the importance of teamwork, problem solving, and design [9], [10]. Imparting such a mindset is now the goal of innovative engineering curriculum across the United States, where through problem-based learning, multidisciplinary teams, collaboration with industry partners and creativity, students are able to envision new solutions to real world engineering problems [9], [10].

## II. PROBLEM-BASED LEARNING

In some ways what problem-based learning (PBL) is seems self-evident: it is learning that results from working with problems [11]. Typically, PBL is described as an instructional strategy in which students confront contextualized, ill-structured problems and strive to find meaningful solutions [12]. It is a method of learning characterized by its flexibility and diversity in which the problem is first introduced, followed by a systematic, student-centered enquiry process [13]. The instructor becomes more of a facilitator as student-to-student learning is critical to this style of learning [14].

Although originating in medical schools, the pedagogy embraced by PBL has found favor in other disciplines [12]. While PBL is relatively new to engineering, it is an approach that is uniquely suited to the discipline as PBL can force engineering students "to seek out and solve problems at the boundaries of the engineering disciplines" [2], [15], [16]. PBL is inherently suited to a small group, team based learning approach. However, the introduction of innovative teaching methodologies which require students to be active learners must be handled with care. This concern is exacerbated when multidisciplinary teams are created forcing students to work with persons whose culture, gender, race, learning styles and knowledge set are likely different from their own. Engineering students must learn how to communicate engineering concepts to non-engineering team members as well as to understand non-engineering requirements, specifications, and ontology.

Case studies are a form of PBL that models classroom assignments around actual, real-world problems in a team environmental effectively linking academics to industry [9], [17]. The case that is presented in the following sections highlights the benefits and challenges for students, faculty and industry who are interested in designing a real-world, multidisciplinary, team-based project into engineering curriculum.

## III. THE PROJECT

The semester (16 weeks) long project required the collaboration of faculty and students from two different departments (engineering and apparel design), located in two different colleges as well as participation from an industry partner. Attracting an industry partner to collaborate on a university classroom project is not difficult if the associated faculty instructors are engaged in practice as well as scholarship and give visibility to their academic programs by actively participating in industry forums (i.e., conferences, seminars) where leaders gather to learn and discuss emerging trends and practices. The main requirements of an industry partner are that they are receptive to the idea of the classroom as a laboratory for testing out new ideas and that they are committed to the project from idea conception through to the evaluation of the project. Alumni of the respective academic programs that are working in the field also make good partners on collaborative projects and serve to strengthen the bond between the alumni and the institution. Such collaborations keep both parties apprised of current practices and learning strategies and are therefore mutually beneficial.

### *A. Project Introduction and Team Formation*

The instructors from both departments met to determine the scope of the problem that students would be working together to solve. It was important that the problem selected be one that intersected both fields and was relevant to the industrial partners. Heat transfer was a topic of common concern to both engineering and apparel design students. An industry partner in the apparel and textile field that developed performance apparel was selected for participation and collaboration. Both engineering and apparel design disciplines use a problem solving approach to design, or what is often called “design process”. The challenge, however, would be in determining how the problem solving strategies would be negotiated between team members from two diverse disciplines. The instructors purposely chose a broad based problem to be solved by the teams, but one with a concrete outcome. Team success would be measured by how the teams worked together to solve the problem and how well the outcome or solution described by the teams resolved the problem.

There were a total of 27 students in the combined course, with 19 apparel students and eight engineering students. Team size was limited to four students to maximize interaction with at least one engineering student to two or three apparel students in each team. A total of seven teams were formed in a manner that ensured one engineer was on each team but was otherwise completely random.

Fortunately, both classes were scheduled to meet at the same times on the same days, making the scheduling of common meeting times between the two classes much easier.

### *B. Problem Identification and Initial Research*

The problem presented to the students was this: Design a garment for the human torso that will facilitate heat transfer considering a particular environment, activity, or both. Groups were randomly assigned one of three conditions: 1) environment and exercise; 2) environment only; 3) exercise only. Three groups ended up with condition 1; two groups with condition 2; and two groups with condition 3.

Each team had the liberty of specifying conditions of the environment and/or activity to which they would be designing. Each team was given access to an infrared thermal camera to examine heat patterns in the human torso (Figure 1), a walk-in environmental chamber in

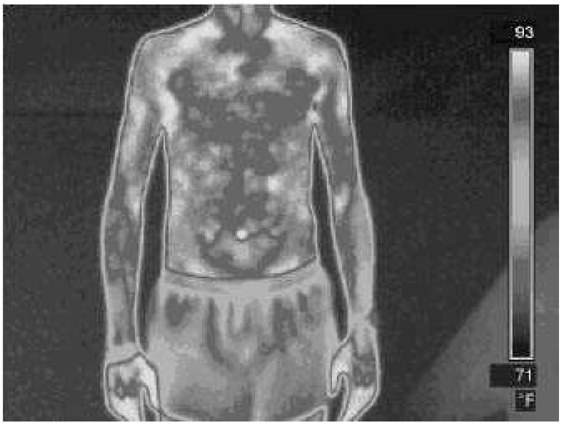


FIGURE 1. SAMPLE THERMAL IMAGE

which they could control both temperature and humidity to the conditions they selected, and a 3D body scanner which produces a 3D point cloud model of the human body (Figure 2) A stationary bicycle and treadmill were made available to the students for simulating activity. All of the equipment was located in one laboratory in the Engineering building. All of the student teams had access to this technology and were tasked with using their creativity to solve problems related to the thermodynamic interaction between apparel and the human body. This combination of equipment also enabled the team to be flexible and dynamic in composition, to most effectively combine the technical and discipline expertise of the individual members.

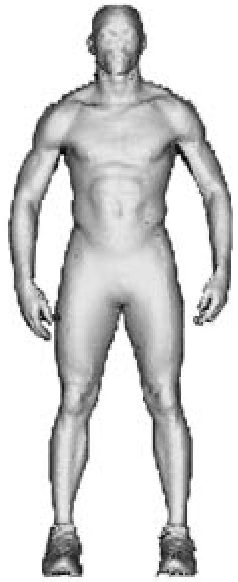

FIGURE 2. 3D BODY IMAGE

Teams wrote up an initial design proposal outlining the parameters of their projects, assigning member responsibilities, and a time line for conducting the work. They were given one 75 minute class period per week for the final 8 weeks of the semester to conduct their work. A fair amount of negotiation took place among the teams so that all activities could be completed within the given time framework. In addition to class time, there were six hours of open lab time per week that teams could utilize for completing the work.

*C. Prototype Development and Testing*

As expected, there was a diversity of outcomes from the groups as they negotiated approaches to the problem and strategies for designing a garment that would facilitate heat transfer in a particular set of circumstances. The task of identifying a particular environment and activity was relatively easy. One group used Michigan summers as the starting point for selecting an environmental temperature; they identified a moderate pace of running as the activity for which the garment would be worn. Another group selected the rainforest for their environment and walking as the activity that would be conducted in that environment. Each group selected a team member to be their subject for testing. They used the infrared camera to document heat patterns in the torso during rest in ambient conditions; and then used the camera in the environmental chamber to examine the subject again under the conditions that they selected. For garment fit, the groups used the body scanner to generate body measurements that would be utilized in the design of their garment.

The materials selected for the garment were selected from a variety of materials - sought from local fabric stores, textile websites, existing garments, and unlikely sources such as food wraps and other found materials. The engineering students examined the materials for thermal resistance while the apparel students examined ways to piece the materials together. The thermal patterns illustrated by the infrared thermography of the subjects and analyzed with existing software provided the major input for the garment design.

There were a variety of questions that the students raised during the process that were not answered by the instructors. For example, is cost a limitation? Does the garment have to be machine washable? Can it be disposable? What about durability? Do component materials have to be compatible? Can it be seamless? How will it be distributed to consumers? By not providing answers to these questions, the questions became even more thought-provoking and served to encourage more discussion and creative thinking among the group members. It also drove home the point of design as "an iterative process" - and that making steps "forward" in the process often resulted in taking steps backward.

*D. Industry Project Review Phase*

It is always advantageous for industry professionals to visit campus at least twice during this collaborative process; preferably at the beginning and at the end of the project. College campuses are teeming with future consumers, future designers and future decision makers across a variety of fields. What are students being exposed to? What are their residences, classrooms, restaurants and social circumstances like? What are their likes, dislikes, tastes and preferences? What technologies are they using and *how* are they using them? Casual observation of students on college campuses are revealing about a number of trends that are potentially prophetic. While busy corporate professionals are usually harried by the time they arrive on campus, they are generally refreshed by the time they leave by the perspective that the college classroom offers.

Student teams presented their project results with industry professionals in the classroom via a formal presentation. Students were instructed to dress professionally and use interactive media technology to present their results. They used the design process as a format for their presentations and ended with a demonstration of their prototypes. The industry partner then had an opportunity to react to the presentation and discuss project results with the students and instructors. The solutions to the problem presented by the teams ranged from creative, provocative, practical or impractical. The dialogue that took place during the evaluation process was invaluable to the students. They heard an evaluation of their work by a professional who participates not only in the real world, but "in the trenches" where the reality of problem solving processes make the difference in marketplace products and processes. Lastly, the students evaluated the semester long project in terms of their own contribution to the team as well as each member's contribution to the team.

*E. Other Project Challenges*

There are both numerous benefits and challenges for students from diverse disciplines. The major benefit for the engineers is the simulated "real-world" experience gained through working with a group of non-technically trained people. After over 3 years of a traditional engineering curriculum, these students have become accustomed to daily interactions with faculty and classmates who are well versed in the engineering sciences. Inevitably, both groups of students experience culture shock as their group dynamic forms. Yet, as each type of student enters their respective professional fields, it is more likely than not that they will be interacting on a daily basis with others who are not accustomed to their areas of expertise. Experiencing this type of professional interaction within the classroom will make both groups of students more marketable and adaptable in the workforce.

Another benefit for engineering and design students is experiencing the stark reality of compromise in the design process. When designing a product for the mass consumer market, the best engineering design is not usually the best overall design. As one recent engineering student confided about his heat dissipation calculations for an active wear T-shirt, "I selected the proper materials for optimum thermal comfort of the wearer, but my group members were quick to point out that no one would buy the finished product because it would look "dorky". Apparel design students may be more aware of the aesthetic design component and the role that it plays in the marketing process.

There are a number of challenges associated with undertaking a collaboration of this type. The most pressing challenge is allocating sufficient time for coverage of the more traditional engineering topics found in a heat transfer course,.. Topics such as external convection, internal convection, and radiation often get minimal coverage which may put the students at a disadvantage when being evaluated by standardized assessment tools such as the Fundamentals of Engineering (FE) Exam. While apparel design students may have less design work to add to their portfolio as a result of time spent on a project of this scope, the advantages of working with engineering students and an industry partner certainly outweigh this disadvantage.

An additional challenge for the faculty was to facilitate positive working relationships among each of the teams' members. Certain teams blossomed into fully functioning groups by sharing work load, compromising during decision making processes, and setting aside self-pride for the common good of the group. Other teams were not as fortunate and struggled with creating a positive and productive group dynamic. The more mature and academically motivated students seemed to best suited for this type of open-ended collaboration. In retrospect, some things (?) that would have aided in team-building but weren't in this particular collaboration include incorporating team-building exercises at the beginning of the project immediately after team formation and mid-project peer evaluations. Establishing simple "ice-breaker" exercises would have formed trust and created a comfort level among the team members early in the project. Mid-project peer evaluations would have provided feedback to the faculty and team members on the perceptions of the team members as to how productive and functional the teams were operating. The peer evaluations would be collected early enough in the project to allow for faculty suggestions on how to make the team more functional. (Should we reference these ideas?)

The ultimate form of assessment will be the feedback from the employers that hire the engineering and design students. Does the benefit of being involved in a highly inter-disciplinary design project such as this collaboration outweigh the cost of a cursory coverage of more traditional classroom topics? If a glimpse of how the "real world" operates in the dynamic and global workplaces of today, it is clear that the benefits of a collaborative classroom experience with an industry partner are superior to more traditional approaches to teaching and learning.

## IV. CONCLUDING REMARKS

Partnerships like these offer students, faculty and industry leaders a wealth of advantages. As a consequence of their involvement, industry professionals meaningfully interact with emerging professionals (students), gain new perspective on students' view of the world, and see how young designers are problem solving and using technology to actively address design issues. Students gain field-relevant skills through exposure to real world problems and interface with senior executives during the presentation and evaluation of their work. Additionally, students with experience working as an effective team member helping to solve a real-world design problem will result in a well-prepared professional who can balance technical training with a firm understanding of scientific inquiry and industry practice. Conversely, faculty securing collaborative opportunities for the classroom become industry ambassadors; empowered through partnership to offer students fresh, relevant curriculum appropriate to the challenges graduates will face in the workplace.

## ACKNOWLEDGMENT

The authors would like to thank the National Science Foundation for their support in obtaining the 3D body scanner, and to Central Michigan University for their 2010 financial support.

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