Graduate Automotive Engineering Education Innovation – Deep Orange Program Collaborative Industry Partnerships Enable System Engineering Based Approach for Project-Focused Learning

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Abstract

Through traditional education associated with engineering disciplines, students are expected to become familiar with fundamental engineering design and principles through a series of engineering materials explanations, stages of assignments and class projects. The usual knowledge flow offered to engineering students is based on a step-by-step process taught by faculty using text books. Design solutions to real world problems often require approaches that cannot be obtained from traditional text books, such as the formulation of meaningful ideas, setting realistic design requirements, learning to execute trade-offs, balancing competing priorities, and communicating with colleagues that have different technical backgrounds. This paper presents the implementation of a system-based, sponsor-partner, collaboration focused, learning approach within the curriculum of the Department of Automotive Engineering at Clemson University which meets these real-world design engineering needs.

The program implementing this real-world approach is called Deep Orange (DO). The Deep Orange initiative is an integral part of the automotive graduate program at the Clemson University International Center for Automotive Research. The initiative was developed to provide first-year graduate engineering students with hands-on experience of the knowledge attained in the various automotive engineering and related disciplines (such as marketing and human factors psychology). The program focuses on developing and building new, innovative vehicle concepts and is driven entirely by graduate automotive engineering and transportation design students as part of their education in close collaboration with industry partners. This paper demonstrates and discusses the flow-down of requirement characteristics of the systems engineering process applied in DO.

During this process, the students start with translating a grand challenge (defined by the sponsoring industry partners) into customer needs incorporating marketing analyses. The project proceeds with general investigation of various vehicle architectures and design alternatives, including the selection of one concept that is based on carefully balanced environmental, economic, performance, and social design imperatives. During the process, faculty serves as student mentors rather than direct knowledge providers. Students are

empowered to make decisions and justify their concept selection to different program groups, i.e. sponsoring industry partners and faculty. The last eight months of each project is devoted to building a physical prototype and validation of the vehicle target requirements.

Introduction

Traditional approaches to engineering education in the US have struggled to provide early-career engineers with the skills and experiences needed to succeed in today's fast changing technical fields. Current engineering educational methodology is generally the same as that employed during the last century and dates back to the early 1940's[1]. In a recent study, the American Society of Mechanical Engineers (ASME) identified aspects of US engineering education that are currently ineffective, with a focus on mechanical engineering[2]. The most significant shortcomings were practical experiences, a general system perspective, an understanding of engineering standards and codes, problem solving skills, critical thinking skills, oral and written communication skills, and project management skills. To close the gap between the current educational state and these identified changes, ASME recommended the following actions for curricular change: (1) Create curricula that inspire innovation and creativity (professional skills such as problem solving, teamwork, entrepreneurship, and project management), (2) Offer more practice-based engineering experiences that are based on design portfolios, (3) Incorporate "Grand Challenges" into the design spine (such as sustainable development, lightweight design, and energy efficiency), and (4) Increase faculty experience in professional practice.

Based on these recommended actions, present engineering education requires fundamental change based on the development of dynamic curricula that rapidly respond to industrial needs and at the same time focus on the requirements of traditional engineering. For example, the design, manufacture, and implementation of efficient road transportation systems requires an integrated application of design concepts from disciplines ranging from engineering and information technology to business management and behavioral science. Many challenges and opportunities for improved design have recently arisen in the road transportation industry as a result of a myriad of often conflicting and ever changing public regulations and policies. The rate of market change has dramatically increased the need for an engineering work force that can manage and lead product development processes that require increased innovation over reduced product development cycles.

Current engineering leaders need to combine expert knowledge in a particular field with the breadth to integrate with related disciplines required for successful product development. They need to interface with other industries as well as collaborate with colleagues whose perspectives are influenced by radically different experiences. In a recent publication Wagner[3] presents core competences that every engineering student must master to gain knowledge for innovation process leadership: (1) Collaboration across networks, (2) Critical thinking and problem solving, (3) Initiative and entrepreneurialism, (4) Agility and adaptability, (5) Assessing and analyzing information, and (6) Effective oral and communication skills.

An engineering education approach to meet these needed skills requires systems focused project-based learning. Studies[4] have shown that this teaching structure can meet the needs for active learning to develop robust professional skills which greatly depend on design and creativity, as in the case of vehicle engineering. The Automotive Engineering Department at the Clemson University International Center for Automotive Research (CUICAR) has implemented an educational framework that incorporates this project-focused approach within a component of graduate curriculum known as Deep Orange (DO). The DO initiative[5] was developed to provide graduate students with hands-on experience of the knowledge in various engineering disciplines and related disciplines (such as marketing and human factors psychology).

Deep Orange Program Overview

The Deep Orange initiative was launched in 2009 as a partnership with the Art Center Transportation Design Department in Pasadena, California. The Automotive Engineering curriculum at Clemson merges the depth (through specialized tracks) and breadth (through the interdisciplinary Deep Orange initiative) into an integrated scholastic experience. DO is a framework that immerses students into the world of a future Original Equipment Manufacturer (OEM) and/or supplier emulating an accelerated product development process for a new vehicle. Working collaboratively, students, multi-disciplinary faculty, and participating industry partners focus on designing and building a new vehicle concept with each new class of students. Industry participation and mentoring plays an essential role in the process.

Each DO project incorporates integrating innovations for breakthrough products and new processes, which provide the students with hands-on experience in multi-disciplinary fields, such as market analysis, value proposition creation, vehicle design, computer-aided engineering, systems integration, prototyping, and design validation from their entry into the automotive engineering program until graduation. The strategic focus of DO is to develop new automotive mobility solutions that address a grand challenge (such as sustainability, safety, health, and wellbeing). Currently, DO is in its seventh series with the two-year program divided into six main design stages (Figure 1).

- Strategy and market assessment, identification of opportunities, and creation of a value proposition
- Ideation, solution formulation, and concept selection
- Concept development (detailed engineering and design)
- System integration (design space, function, production)
- Prototype build and assembly
- Product validation and target confirmation

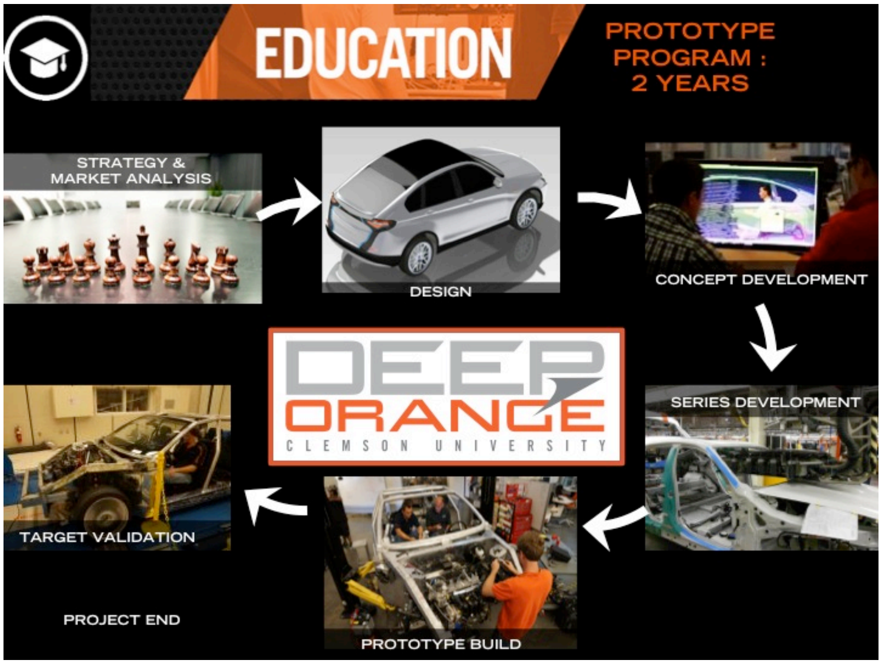

Figure 1. Six Main Design Stages for the Deep Orange Program

The development cycle for the vehicle design initiates the project with the value proposition and definition of customer needs. The students are required to justify all of the generated program solutions and concepts within the context of the derived customer needs. This design methodology allows for the confirmation of design specifications to the initial targets.

Deep Orange Educational Components

In order to achieve a robust and effective systems engineering approach for project-based learning, DO utilizes the following educational components.

•**Design Requirements Flow-Down.** All of the major design activities are driven by systems engineering principles derived from customer needs and vehicle performance/content standards. During the first stage of DO, students participate in a strategic phase of market and trend analysis, including data mining vehicle owner surveys. The goal of this stage is to develop the student's ability to identify an opportunity/need and to relate "pure" engineering design concepts to real-world customer desires. The challenge consists of translating non-technical customer responses into engineering requirements for a vehicle. The flow-down process is supported by the benchmarking of competitive vehicles available in the market. The CUICAR faculty provides support through mentoring rather than defining a design problem statement.

•**Concept Ideation.** The development of a vehicle prototype, which should be market competitive, is an open-ended design problem that challenges students to explore and arrive at different design alternatives at both the vehicle system and component level. DO students learn in an order opposite to that of traditional education approaches, where students search for answers, derive conclusions, make decisions, and justify design selections within managerial, social, economic, and engineering constraints. At this phase of the DO program, students are divided into teams, including but not limited to major vehicle subsystems such as powertrain, chassis, vehicle body, interior, vehicle electronics, and project management.

•**Design, Demonstration and Visualization.** After initializing a design with customer needs in mind, the DO process requires students to visualize a final vehicle prototype by mapping the relationship between customer requirements and a design solution. The design stages that define this mapping include building mock-ups and prototypes that enhance visualization of a final design. At this program stage it is more helpful to the students to view a physical structure rather than a digital visualization of the design.

•**Decision Making.** The students are the main drivers of the DO design process. A high level of engagement empowers them to make fundamental design decisions as well as decide when ideal vehicle characteristics must be eliminated due to time and budget constraints. Through faculty engagement, the students are taught to make their ideas transparent and translate them into final concepts that meet customer requirements and program engineering targets. They are taught to make decision matrices that balance competing vehicle properties (cost, weight, packaging, functional performance) and learn how to implement design trade-offs.

•**Design Review Feedback.** The DO framework has preset design reviews with increasing levels of design completion, which include faculty, industrial partners, and suppliers. Hence, students learn to critique their own work as well as provide and receive feedback. This is an essential element of DO learning that enables the students to think critically, particularly with regard to the impact of their component or system design on the overall vehicle concept.

•**Results, Presentation and Documentation.** During each phase of a DO program, students are responsible for documenting their work (including decisions/mistakes and rejected solutions) in an evidence book. In addition, they are required to present their immediate and final design to various audiences (faculty, industrial sponsors, professional society engineers) and attend industry trade shows to market their project outcomes.

Role of Collaboration

•**Industry Partnerships.** DO relies extensively on close collaboration with multiple industry partners. Partners range from OEMs and aftermarket suppliers to small engineering entrepreneurs. The partnership roles include providing realistic examples of problems in industry that highlight engineering challenges and associated design requirements to provide the students concrete examples of trade-offs which are fundamental to a systems engineering design approach. In addition, the industrial collaborators mentor the students and offer feedback during each phase of the project. The students are frequently involved in one-on-one partner meetings to resolve technical issues. These interactions between students and mentors are of great student benefit since the feedback is given from a practical industrial viewpoint. In addition to this valuable feedback, the partnerships offer access to technological tools and innovative processes/materials that are currently used by participating partners.

•**Interdisciplinary Design.** The DO vehicle exterior and interior design is developed through a 42-week collaboration between the program design center sponsor faculty and the CUICAR engineering students/faculty. A collaboration team synchronizes design related milestones for the program creation phase. In this phase, a small team of automotive engineering students is assigned to one transportation design student to jointly generate a vehicle concept. This partnership enables the students to investigate creative options and propose unique vehicle concepts that are both functionally feasible (engineering input) and aesthetically desirable (design input). The collaboration between two educational institutions creates challenges due to the fact that students must communicate from different geographic locations (South Carolina and California) with different classroom schedules and a 3-hour time difference. The partnering also requires the students from both institutions to translate and convey the customer/engineering/artistic requirements into a mutual, graphics-based language to discuss the feasibility and desirability of the concepts developed.

•**Research Innovation.** A primary goal of the DO program is to apply new and innovative solutions in the design, engineering, and manufacturing of a concept vehicle. As the program continues to mature, one CUICAR objective is to enable more PhD students to consider the use of DO vehicles in their research work or to incorporate new research technologies into DO. This opportunity can serve to define future trends in the design and manufacture of vehicles. One example of a PhD research project that was incorporated into a DO project is the doctoral work investigating the design analysis of origami folded sheet metal[6].

Deep Orange Program Outcomes

To date, six Deep Orange Programs have been completed:

•**DO1 "Future Electric Mobility"** (Completed in 2010, sponsored by BMW). DO1 focused on the integration of powertrain, energy storage, seating concept, and infotainment elements in one vehicle. A baseline vehicle was converted into a range-extended, plug-in hybrid-electric vehicle with a unique seat attachment architecture that mounts the seats backrest to both the roof and floor of the vehicle. In addition, the vehicle interior instrumentation relied solely on a portable Smartphone device, in combination with a cloud-storage concept.

Figure 2. Deep Orange 1: A Concept Created for Generation Y

•DO2 "Future Digital Cockpit Experience" (Completed in 2011, sponsored by BMW). DO2 focused on the development and implementation of a digital reconfigurable vehicle cockpit for the DO1 vehicle. It demonstrated a new Human Machine Interface (HMI) and center stack design that allowed for personalized, intergenerational driver interaction with various vehicle, infotainment, and climate controls. Multiple usability tests were conducted including students from the automotive engineering, computer science design, and human factors programs.

Figure 3. Deep Orange 2: Human Machine Interface

•DO3 "The Next Big Thing" (Completed in 2012, sponsored by Mazda). DO3 was a fully-functional hybrid mainstream sports car concept targeted towards Generation Y. The vehicle concept developed was given the name "Next BIG Thing" with a target start-of-production in 2015 and was the first program vehicle built from scratch. The vehicle has a through-the-road parallel hybrid powertrain concept with a manual transmission. The concept design employs a 6-seater interior concept and body structure made of origami folded sheet metal.

Figure 4. Deep Orange 3: A Hybrid Mainstream Sports Car

•**DO4 "Transformative Activity Vehicle"** (Completed in 2014, sponsored by BMW). DO4 focused on the transformation of a baseline luxury Sport Utility Vehicle (SUV) into a pick-up style truck. A sliding glass roof transformed the hatch compartment from an enclosed area into an open-bed configuration. The interior was designed to seal off the passengers' cabin. In addition, a new rear seat design was developed to meet the storage requirements.

Figure 5. Deep Orange 4: Style and Versatility

•**DO5 "Personal Emotional Urban Mobility for Generation Y/Z"** (Completed in 2014, sponsored by Chevrolet). DO5 is about creating a better value proposition for young adults that have little money to spare, that have less interest in vehicle ownership, need a personal mobility solution for commuting and shopping at the lowest cost of ownership, and have the desire for extra space, and performance for leisure activities. In addition, the project is about creating a solution where social networking and mobility go hand-in-hand, ultimately creating an emotional connection with the vehicle, which leads to the creation of a mobility lifestyle.

Figure 6. Deep Orange 5: Urban Mobility for Generation Y & Z

•**DO6 "Urban Utility for Generation Z"** (Completed in 2016, sponsored by Toyota). DO6 focused on the development of a blank-sheet, youth oriented vehicle concept with a targeted US market introduction of 2020, catering equally to both young males and females. The vehicle has a low, completely flat interior floor with removable seats. This seating flexibility was achieved by a space-efficient and compact packaging concept for the electrified powertrain architecture. Replaceable "snaps" and "tracks" in the rear cargo area have simple to use interfaces that allow for numerous utility configurations.

Figure 7. Deep Orange 6: An Urban Utility Vehicle

Conclusion

The goal of the Deep Orange Program is to place academic knowledge into context and to tackle complex vehicle design and prototyping through industry-academic partnering. DO provides a systems engineering-focused framework that over a span of 24 months prepares graduate automotive students for the rigors of industry. It provides to them hands-on experience in designing, engineering, producing, and validating a vehicle and gives them exposure to fundamental aspects of engineering and prototyping. DO provides a development environment for pioneering new methods and technologies for structural design and manufacturing and feeds new knowledge gained back to both industry and academia. The studio learning environment and application of industry-relevant teaching and mentoring methods provide a close alignment of academic and industry practices. Ultimately, DO prepares engineers to quickly assume responsibility and to embrace new team roles and challenges that the automotive industry will face in years to come.

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