AC 2010-31: WESTERN WASHINGTON UNIVERSITY'S HYBRID BUS - A MULTIDISCIPLINARY APPROACH TO PROJECT BASED EDUCATION

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Western Washington University’s Hybrid Bus – A Multidisciplinary Approach to Project-Based Education

Abstract

Western Washington University (WWU) has initiated a research, design and build project that is focusing on providing a fuel efficient, low floor, hybrid electric shuttle bus that is intended for a variety of applications. The primary R&D team is comprised of undergraduate students and faculty from the Engineering Technology (ET) Department and industry representatives from key areas. The design process has intentionally followed a multidisciplinary approach which seeks to utilize skills and capabilities from a range of students across the ET Department, and will soon reach out to work with students and faculty in the Chemistry, Decision Sciences and Marketing departments here on campus. The multidisciplinary team concept helps students to recognize the importance of bringing people with areas of specialized expertise together to collaboratively solve problems, while gaining an appreciation for alternative perspectives.

While the concept of project-based instruction is not new, the project at hand is unique in that it is providing the students the opportunity to apply the theoretical concepts obtained in the classroom to a real world application that is headed for production implementation. Transit groups from around Washington State have come together to assist in defining a set of desired requirements that current products are failing to meet, which include improved fuel economy levels, efficient handling of disabled passengers, and driver and service operational enhancements. This same group is committing to purchasing initial production units once the new vehicle has successfully passed Federal Transit Administration (FTA) certification testing. The project provides exposure to a very real industry application which is similar to what many of the students will face when entering their career fields, and will allow for practical application of project planning, design innovation, budgeting, working with industry standards and government regulations, as well as manufacturing process planning and execution.

An industrial approach is being utilized for the design process which emphasizes use of several automotive industry best practices including Quality Function Deployment (QFD), Design Failure Mode Effects and Analysis (DFMEA), as well as Design for Manufacturing, Design for Assembly, Design for Service, and Design for Sustainability, which are all components of industry accepted quality management tools and the “six sigma” philosophy. The R&D team has been set up to model a “skunkworks” approach, which was developed during World War II by engineers at Lockheed Martin who were looking to deliver a jet fighter to the US government in a short time period. This approach has been successfully used in automotive projects, and other disciplines, and is characterized by its autonomous structure with empowered workers who move quickly to resolve issues, leverage expertise from outside of the core team (ie. multidisciplinary approach), and are able to accelerate product design and development activities in comparison to more conventional approaches.
This paper will discuss the benefits of project-based education by highlighting the instructional activities and progress of the project to date, with specific focus on the attributes associated with a multidisciplinary, skunkworks team approach.

Background

The WWU Hybrid Bus project was initiated in the summer of 2007 as a research effort to explore potential methods for improving school bus fuel economy levels and passenger safety. From previous experience as a public school system board of education member, it was disturbing to discover the continually increasing level of funding that was diverted away from instruction and redirected toward transportation fuel costs, and on an unrelated issue, of the high degree of student injuries occurring on the bus steps upon entrance and exit (second only to playground injuries). Thoughts of developing a low-floor vehicle to eliminate entrance steps, with a fuel efficient hybrid electric powertrain, as well as improvements in driver handling capability and passenger ergonomics, were the initial focus for the new bus concept. A subsequent meeting with Mr. Richard Hayes, Kitsap Transit Executive Director, resulted in discussion of similar concerns for the paratransit shuttle services that his organization provides to its customers in the Puget Sound area. Paratransit service is defined as being on-demand transportation, with no fixed route, which is primarily utilized by disabled or elderly customers, and by those that are unable to provide their own means of transportation. Kitsap Transit and other transportation providers have indicated an urgent need to acquire a vehicle capable of achieving significantly higher fuel economy levels than the 26-39 L/100km (6-9 mpg) average fleet values for their vehicles in the 6.1-9.1 m (20-30 foot) length range. The transit groups also expressed concern over the frequency of passenger and driver injury associated with the hydraulic lifts used for loading wheelchair-bound passengers, and the increased loading time associated with these devices. Delivery of a more fuel efficient vehicle with improved customer access was not on the radar screen for current vehicle manufacturers. Due to the highly competitive market, continued cost-cutting measures, and the unwillingness to depart from conventional cab and chassis architectures, original equipment manufacturers (OEM’s) are not able to provide radically different product offerings which are being sought by transit agencies. Based on the R&D team’s goal of providing a modular bus design with reconfigurable interior, it was determined that the needs of school transportation providers and transit agencies could be met with the same base product. Additionally, through the potential funding sources and access to industry resources that the transit agencies possess, it was determined that development of the initial prototype vehicle would target the transit based platform.

In February of 2008, a workshop was held on the WWU campus that involved representatives from more than twenty regional transit agencies, national and local government office representatives, and transportation related community groups, who were tasked with the goal of establishing base requirements for the new hybrid bus design. The student team facilitated several of the activities, which included focused brainstorming sessions and a trip to the Whatcom Transit Authority’s service facility in Bellingham, Washington, to enable a thorough evaluation of current vehicle technology while on the lift. Through this workshop, and the continued benchmarking and design analysis efforts
of the R&D team, a preliminary design specification sheet has been created and is attached as Appendix A.

The Vehicle Research Institute (VRI) exists within the WWU Engineering Technology Department. Established in 1975 by Dr. Michael Seal, this institution serves as the research arm of the Industrial Technology - Vehicle Design (IT-VD) program, and provides the base facilities for many of the research projects and curricular based activities. At the present time, there are more than (45) vehicles that have been designed and built through this facility, which take on the successive Viking car numbers, including the Society of Automotive Engineers (SAE) Baja and Formula design competition vehicles, which are purpose-built, student-only projects. The remaining Viking car projects, named after the school mascot, have focused on lightweight, alternatively fueled hybrid electric, and full electric vehicles. Past projects include Viking 20, built in 1990, which is a solar electric vehicle that placed 2nd in the GM Sunrayce and 5th in the 1990 World Solar Challenge in Australia, and Viking 45, which is currently being built to compete in the 2010 Progressive Insurance Automotive X-Prize Competition, with minimum entry qualifications of 2.3 L/100km (100mpg), and the requirement of being able to build 10,000 units per year. Viking 45 is a custom carbon fiber body / chassis construction with a modified Honda Insight hybrid powertrain, and is targeted to weigh in at 500kg (1100 lb). It is one of only three competition entries from educational institutions worldwide.

Figure 1 - WWU VRI Viking 20

Figure 2 - WWU VRI Viking 45 Rendering

Project- Based Instruction

Project-based instruction, as presented in this paper, is intended to compliment the theoretical concepts introduced during classroom discussions by serving as a concrete means of reinforcing abstract concepts, and to provide a tactile learning environment for hands-on experience. This concept is further emphasized by experientialist philosopher, John Dewey, when defining experimentalism, or hands-on, inquiry-based instruction as “reconstruction or reorganization of experience which adds to the meaning of experience, and which increases ability to direct the course of subsequent experiences.”2 At the turn of the 20th century Dewey was a primary advocate for the progressive
philosophy of education and was a strong influence for the experimental methods of instruction and learning that exist in education systems today. As Dewey suggests, through experimentation with practical applications, the student educational experience is enhanced as they are able to make a connection through multiple sensory stimulation and are better able to apply the knowledge gained to future problems that build upon that experience. According to Hlebowitsh, “...the whole child must be educated, not just the mind [and]...curriculum, as a result is comprehensive in its scope, is interdisciplinary in its overall organization and is activity-based in its sense of experience.”

The entire WWU ET Department, and specifically the IT-VD program, embraces this philosophy and provides a wide range of hands-on educational experiences for the students to engage in during their courses of study. While the initial design phase of the Hybrid Bus project has limited classical hands-on lab experimentation activities, the concept of a specific vehicle with many established design targets serves as a concrete base for utilizing analysis and optimization techniques discussed in class, and increases the opportunity for more tangible comprehension of the results. The author suggests that project-based instruction is an extension of the experientialist philosophy as it links the inquiry based instruction methods to the use of analytical tools used in the virtual “lap top lab” by students as they optimize design details. Examples of analytical tools used by the R&D team include a spreadsheet that was developed for powertrain and battery pack sizing and selection, CAD models of exterior and interior design concepts, and the QFD and DFMEA matrices used for design feature prioritization and analyses. As witnessed in the previous Viking cars built, the more intensive, physical hands-on lab experience is encountered as the design takes shape, elements are tested in the physical labs, and prototype vehicle fabrication and assembly progress.

Elements of the Hybrid Bus project have been utilized as activities in a range of courses within the ET Department and will soon expand beyond the department to others within the College of Science and Technology, and the College of Business and Economics. The following is a discussion of recent project-based instructional activities that were used in courses that involved subject matter that was able to be modified to allow specific focus on the Hybrid Bus application details.

Once an understanding of the basic customer requirements was obtained from the previously discussed workshop, and further discussions with the transit representatives occurred, taking cues from the automotive industry, the quality function deployment process was used to establish a prioritized listing of requirements and assist with design implementation. This activity was incorporated into lecture and lab sessions for a Industrial Quality Assurance (IQA) course that the author provided, which is open to all six major areas of study within the ET Department. WWU’s course curricula are designed around the quarter system, which allows for nine structured labs for the ten week quarter, assuming that one unique area of content is covered each week. QFD was already an area of discussion for the “Quality of Design” section of the course, so that coverage of the hybrid bus topic was easy to accommodate. The class of (36) students was divided into (3) lab sessions, with each lab group selecting one of the major areas to focus on, which included Body / Chassis, Powertrain / Drivetrain or Interior Design. The lecture at the start of the week provided an introduction to the QFD process, discussed both positive and negative attributes, and reviewed the standard format of data presentation
used. A negative aspect of QFD, which the groups would later learn, is that it can be an extremely time consuming activity, if done thoroughly. The labs went well with enthusiastic participation by the majority of the students, as many had not previously been part of a functional team that was tasked with analyzing a product that had a high probability of heading into production. It should be noted that in a typical lab session there were 2-3 students that were either part of the core R&D team, or were familiar with the bus project, so that they were able to assist with detailed discussions and link the activity back to the project. For the rest of the students it still provided the “tangible link” to an actual product, and most were able to call on their own experiences with riding a bus. The element of being able to draw on personal experience is a significant means for strengthening critical analysis of problems, as it provides a more familiar baseline of “autobiographical knowledge” as opposed to a hypothetical situation that may be presented to the learner. Slattery, in his discussion of postmodern educational philosophy and the criticality of building upon the learner’s own experiences suggests that “…all interpreting and bracketing of events must be directed toward an autobiographical synthesis.”

While there are not always past experiences to draw upon when approaching new territory, we are fortunate that the project content is in an area that has been experienced by a great number of students in public education, and a society that values its high degree of mobility.

A QFD matrix was created in MS Excel format, which provided the students with a template for their analyses that could be duplicated later on if they were required to conduct this type of analysis during their future careers. The QFD matrix is set up with critical customer requirements listed in a column with their associated priority ranking (1-5 with 1’s being low; 5’s high). Potential design solutions or aspects that could assist with meeting the requirements are listed in a row that is perpendicular to the requirements. Relationship matrix points are assigned to each of the cells that link a requirement to a solution (0,1,3,9 with 0’s being low; 9’s high), in order to determine if a potential design solution can address multiple requirements. A technical difficulty rating is assigned based on the ease of implementation (1-5 with 1 being easy), and objective targets are established as benchmark goals. In keeping with the sustainable design approach, and drawing on previous lectures that discussed the perspectives of multiple customers needs for the same product, the analyses were conducted from the viewpoint of bus driver, passenger and fleet operator. Based on the lab and lecture time constraints, we selected 6-10 critical items from each of the customer groups’ perspectives, including those from the previously discussed group workshop, and proceeded to analyze their significance. It was quickly discovered that the two hour allocated lab time was insufficient for completing the entire matrix, so that additional time was provided in subsequent group lecture classes. While the full matrix was not completed due to time constraints, the analyses did provide initial results that allowed the groups to be able to visualize the items that the R&D team should focus on. An example of one of the partially completed matrices, provided in Figure 3, indicates that the priorities for interior design should include an optimized wheel chair ramp, ADA (Americans with Disabilities Act) compliant aisle ways and access, and a centrally located, forward placed driver. This was determined by evaluating the technical importance value, which was arrived at by summing the products of individual requirement priority ratings and design solution relationship matrix value, for each design solution.
## QUALITY FUNCTION DEPLOYMENT MATRIX

### PRODUCT LINE
Hybrid Bus

### MAJOR SUBSYSTEM
Interior

### DESIGN SOLUTIONS
-Centrally Located Driver
-Forward Placed Driver
-Driver Concave Mirror
-Optimized Wheelchair Ramp
-Easy Access To Controls
-ADA Compliant Access and Accesories

### PRIORITY {1-5; 5 = High}
- 1

### RELATIONSHIP MATRIX {9, 3, 1, 0; 9 = Strong}
- CalStart/WestStart
- Hybrid Truck
- Users Forum

### CUSTOMER REQUIREMENTS
#### BUS INTERIOR
- **DRIVER**
  - Road Visibility: 5
  - Passenger Visibility: 3
  - Comfort/Ergonomics: 4
  - Vehicular Interface: 4
  - Safety: 1
  - Disabled Passenger Accommodation: 5

#### PASSENGER
- Disabled Access Improvements: 3
- Emergency Exits/Survivability: 5
- Luxury Amenities: 2
- General Ergonomics: 3
- Easy Access: 5
- External Sound Damping: 3

#### FLEET OPERATOR
- Durability: 5
- Light Weight: 2
- Serviceability: 5
- Survivability: 5
- Maintenance (Hoseability): 4
- Maximum Seating: 5

### PERFORMANCE CRITERIA
- Overall Rating: 1
- Safety: 5
- Road Visibility: 5
- Passenger Visibility: 3
- Comfort/Ergonomics: 4
- Vehicular Interface: 4
- Safety: 1
- Disabled Passenger Accommodation: 5
- Luxury Amenities: 2
- General Ergonomics: 3
- Easy Access: 5
- External Sound Damping: 3
- Durability: 5
- Light Weight: 2
- Serviceability: 5
- Survivability: 5
- Maintenance (Hoseability): 4
- Maximum Seating: 5

### OPTIMAL TARGET VALUES

### TECHNICAL DIFFICULTY {1-5; 5 = High}

### OBJECTIVE TARGET VALUES

### TECHNICAL IMPORTANCE { Sum (Priority x RM) }
Assessment of the IQA assignment involves review of the individual student lab summaries which are provided by the students upon completion of the lab activity each week. In this instance, due to the extended time required for completion, it was a two-week summary. All lab summaries must conform to a format provided to the students which resembles a professional lab report that they will most likely encounter during their careers. A rubric is also provided for each lab activity which indicates critical areas of focus for grading, and assists in reducing subjectivity of final grades. The lab summary includes discussion of the shared QFD matrix developed by the group, but also requires feedback on individual roles and interpretation of the results. Based on rubric details, which include use of proper summary format, strength of discussion/content, level of completion of QFD matrix, and individual participation, an A-F grade is provided.

Additional examples of project-based instruction extending into the classroom include the research assignments made in the IT-VD Power Mechanics and Advanced Power Transmission courses the author has provided. Students were requested to provide formal group written summaries and presentations on alternative fuel options that they were interested in researching. To initiate the assignment, a range of fuels was provided as potential research options, as well as the opportunity to select a fuel of interest that was not on the pre-established list. A brief discussion of the Hybrid Bus project provided a base vehicle to focus their research efforts on, as well as gain perspective on the application elements of the assignment which included a discussion of feedstocks, production methods, performance characteristics, on-board fuel storage, infrastructure issues, including practicality of public/fleet operator use, and conventional internal combustion (IC) engine conversion issues. This assignment is one that is continually requested of the ETEC 280 Power Mechanics classes, due to its relevancy toward ongoing global petroleum based fuel concerns, and the fact that it fits well within the major curriculum focus. One of the major project related impacts from this assignment has been the realization that there are several viable fuel alternatives to mainstream petroleum based products, and that local feedstock availability could play a major role in regional fuel selections in the future. By reducing costs associated with transporting feedstock or processed fuel from outside of the using region, the reduction in fleet operating fuel costs should be reduced as well. Additionally, the impact on the local economy, whether it is farmers growing soy beans or switch grass, or local waste treatment facilities providing refined methane, provides increased regional economic stability and beneficial “grown here - processed here - distributed here” collaborative industry.

Efforts from the fuels research activity have determined the need for a modular approach to fuel use on the Hybrid Bus. The initial prototype hybrid vehicle is planned to be built with a spark ignition (SI) engine converted to run on biomethane, as WWU is concurrently working on a project with local Washington farmers to convert dairy cow waste into methane, and the transit operators are working on agreements with local municipal sewage treatment plants for the utilization of surplus methane for powering buses. The bus chassis is being designed to readily accommodate SI and compression ignition (CI) engines, and hybrid powertrain control systems are being developed with open source control strategies to allow for “factory ready” powertrains capable of running on a wide variety of regional fuel sources. Additional project related activity is planned to determine unique
hardware requirements and potential compatibility issues with non-conventional fuels, but this is beyond the scope of the first Power Mechanics course curriculum.

As this is a substantial writing assignment, the students are required to submit a rough draft that is reviewed by their peer groups, to enable enhancement before final document submission. Assessment of the research paper is fairly straightforward, and also utilizes a rubric to reduce subjectivity of the final grade awarded. The rubric reflects both small group activity associated with the research, writing and formal presentation aspects, as well as individual contributions toward the group effort. A portion of the individual student grade is determined by their peers within the small group, and relies on group cohesiveness and overall results.

A similar assignment was made for the ETEC 381 Advanced Power Transmission course, except that it is targeted toward drivetrain components, or more specifically, IC engine required transmissions and drivelines, as opposed to the powertrain assignment previously discussed, which pertains more to the power sources. The assignment format is identical to the former and requires research, a written summary and presentation by small groups. The detail elements are unique in that a range of potential “latest technology” hardware systems are provided as potential candidates, with the option for students to explore their own areas of interest. Current options include 6+ speed manual transmissions, 6+ speed automatic transmissions, continuously variable transmissions (CVT), automated manual transmissions, dual clutch transmissions, hydrostatic transmissions and infinitely variable transmissions (IVT). Critical research elements include a review of current / intended vehicle applications, advantages and disadvantages of the technology, feasibility of consumer acceptance (as a rider on the bus, and in passenger car applications) and hybrid vehicle compatibility. The author has only provided this course once, so there is not as much student work results to summarize; however, the group found that based on the bus application, several of the proposed hardware systems would not be a good choice, such as the manual transmission, due to clutch service concerns and driver training issues, as well as the CVT, which may not have the durability levels required for the stop and go bus routes and high mileage life cycle. The current design direction for the bus is targeting use of an IVT in conjunction with a powersplit system, which is similar to that used in the Toyota Prius. The powersplit system will feel like an automatic transmission to the driver, however power will be able to flow from the IC engine, electric motor, or a combination of both. Also, similar to the previous assignment, this activity allows for self-directed research, specific application targeting, and the ability to internalize and analyze critical operating characteristics as they impact product function. These project-based experiences assist the students with making the connection between theoretical function and application-specific requirements, which results in a more thorough understanding of functional aspects. These assignment will continue to be offered for future courses and will likely be modified as results from the hybrid bus project are obtained, or technology enhancements are offered in the market. Assessment of this small group project is similar to the previously discussed ETEC 280 research paper assignment.

An additional project-based instructional activity within the IT-VD major is being offered in the Advanced Vehicle Design course provided by a colleague. Course content includes body design,
aerodynamics, interior ergonomics, interior and exterior feature design, and offers the students an
opportunity to design and construct a scale wind tunnel test model. The concepts covered in class are
directly related to critical aspects of the bus design and include floor plan design, passenger seating,
body styling and aerodynamic considerations. One of the assignments that is required of the students is
to select or design a body configuration that they will optimize and test on the 1/10 scale wind tunnel
test machine located in the VRI. Several of the students have either accepted the challenge to design a
bus body, or are on the core R&D team, and have developed three-dimensional CAD models and
physical models of potential bus body designs. This assignment is a classic representation of
experientialism, as it allows the student the opportunity to gain an understanding of a complex concept
in the classroom, such as vehicle aerodynamics, establish a design in CAD to simulate the
aerodynamic features, and adds the element of constructing a physical model in the lab for physical
testing. Several vehicle models have been tested; however, the results were not available at the time of
this paper publication. The scale models have been retained by the author and will be group tested in
the near future in order to obtain cues from the variety of successful styling details, and allow for
implementation on the final bus body design. Assessment of these activities relies on design portfolio
review and evaluation of the final physical models produced in class.

Interdisciplinary Design Approach

Stepping outside of the IT-VD major, yet still within the ET Department, the Industrial Design
(ID) faculty and students have been instrumental in providing the “face” of the Hybrid Bus project
through development of exterior and interior conceptual renderings that have served as visual
representations of the vehicle for informational and public relations purposes. A colleague in the ID
program has collaborated with the R&D team by developing assignments for his students in the ETEC
316 and ETEC 318 courses, which required the students to form small groups and provide interior and
exterior renderings that continue to provide food for thought for the finalized design details. The
assignment started out by bringing members of the R&D team into the ID class for discussion of the
project details and basic customer and R&D team defined requirements related to their specific areas
of interest. A week after the initial meeting, the R&D team was called back in to evaluate hand
sketches and computer generated drawings, provide feedback on ID student progress, and answer
questions that arose after taking a deeper dive into the project. A week later the R&D team was called
back in for oral and video presentations by the ID student teams, and was presented with bound hard
copies of the design work. Two such activities have been completed over the past year, which have not
only provided the basis for design direction in many areas, but have served as a means for student team
collaboration between the two programs, and allowed for a better understanding of the capabilities and
work activities that each discipline is involved with. Since the first round of ID student involvement,
the R&D team has adopted two ID student members as part of the core R&D team, whose involvement
serves to strengthen the overall effort due to their alternate perspective and the collaboration amongst
the two disciplines. Assessment of the ID student activities is completed by their faculty and includes
grading of the overall quality of conceptual renderings, quality of formal presentations to the
“customer” Hybrid Bus R&D Team, and the perceived ability to meet customer defined requirements in their respective areas of proposal.

Students in a range of disciplines have completed a total of twenty directed independent study courses since the start of the project. While the areas of study vary, the same basic requirements apply for all students taking on a Hybrid Bus Project independent study course, and include:

- Submission of a well defined proposal including a project timing plan in MS Project
- An agreement on and description of specific deliverables at the conclusion of the course (dependant on number of credits sought)
- Completion of a detailed project journal for tracking daily activity
- A written summary of their research and design efforts
- Completed design selection matrix / justification of design direction
- CAD drawings and/or hardware (based on negotiated individual course requirements)
- A formal presentation of their results to the Hybrid Bus R&D team

The courses of independent study are set up to allow the students latitude in selecting their topics, methods of approach and level of deliverables; however, the common required elements indicated above provide for a diverse coverage of activities and elements they are likely to encounter when taking on projects in industry. In addition, the students engaged in courses of independent study for the Hybrid Bus Project are invited to join the R&D team in an effort to improve communications and provide a means for interaction for all involved during weekly meetings. It has been found that the students involved in such research projects provide a means for peaking curiosity and building self-confidence in those students that have yet to experiment with this type of educational tool. The enthusiasm from the presenters and obvious degree of knowledge portrayed during these activities has provided the others with a weapon to combat their feelings of angst toward this type of activity. “When students have a choice of topic, have time to really investigate something of interest, can be given responsibility, and can see an authentic …goal and rationale, intrinsic motivation and a heightened sense of alertness and interest becomes a natural by-product.”

A summary of the independent study courses completed to date, including student discipline of study and a brief statement of project impact, are listed in Table 1.

Near term future work will provide the opportunity to involve additional students from a variety of disciplines within the ET department and its associated College of Science and Technology, as well as across campus to the College of Business and Economics. Topics for directed independent study are being developed to allow further collaboration amongst multiple disciplines, and to create opportunities for additional members to join the core R&D project team. Planned courses of study include further research and development of thermoplastic and bio-polymer materials and resins for structural component application, which are targeted at our Plastics Engineering and Chemistry students, as well as base logic and system design for the hybrid powertrain controls, which is targeted toward our IT-VD and Electrical Engineering Technology students. Additional independent study topics that are being developed include the creation of a website for public relations and funding
solicitation, which will be targeted at our Computer Science students, and prototype and production process planning that will target our Decision Sciences and Manufacturing Engineering Technology students.

The independent study projects will continue to provide a means for engagement of students in more self-directed learning activities that allow for deeper understanding in selected areas. The majority of these courses have been targeted toward individual participants; however, several have utilized collaborative workgroups of 2-3 students. In these instances, the workgroups have been directed to dive deeper into content, cover a broader range of associated content, or provide more intensive coverage and/or a higher level of deliverables. While the presumption of independent, individual, or isolated activity is typically associated with these types of study programs, the small workgroups have been very successful, and the “individual” students remain in constant communication with the Faculty Advisor and the larger R&D Team, who provide a sounding board and means for continued collaboration on this large scale project.

<table>
<thead>
<tr>
<th>Independent Study Topic</th>
<th>Student Discipline Area</th>
<th>Project Impact / Knowledge Gained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Requirements Survey</td>
<td>IT – Vehicle Design</td>
<td>Gained perspectives in key areas from multiple customer types (driver, passenger, fleet operator)</td>
</tr>
<tr>
<td>Alternative Fuels (2)</td>
<td>IT – Vehicle Design</td>
<td>Alternative fuels research</td>
</tr>
<tr>
<td>Alternative Fuels</td>
<td>Manufacturing Eng. Technology</td>
<td>Alternative fuels / IC engine compatibility</td>
</tr>
<tr>
<td>Bio-Polymer Research</td>
<td>Plastics Engineering Technology</td>
<td>Current vehicle application / available materials</td>
</tr>
<tr>
<td>Solar Power Battery Charger</td>
<td>IT – Vehicle Design</td>
<td>On-board solar battery charger feasibility</td>
</tr>
<tr>
<td>Composite Chassis Design &amp;</td>
<td>CAD / CAM Eng. Technology</td>
<td>Developed preliminary monocoque chassis / body design &amp; completed FEA on base chassis</td>
</tr>
<tr>
<td>Finite Element Analysis (FEA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powertrain Analysis Tools</td>
<td>IT – Vehicle Design</td>
<td>Enhanced powertrain sizing / performance modeling tool</td>
</tr>
<tr>
<td>Alternative Vehicle E-Power Source</td>
<td>IT – Vehicle Design</td>
<td>Researched ultra-capacitor technology for launch assist</td>
</tr>
<tr>
<td>Bus Suspension Design (2)</td>
<td>IT – Vehicle Design</td>
<td>Provided design options for suspension system design and integration</td>
</tr>
<tr>
<td>Bio-Polymer Research</td>
<td>Plastics Eng. / Vehicle Eng. Tech.</td>
<td>Determined bio-polymer fiber / resin materials difficult to obtain; shift focus to thermoplastics</td>
</tr>
<tr>
<td>Capacitor Power Systems</td>
<td>IT – Vehicle Design</td>
<td>Researched ultra-capacitor technology for auxiliary systems support</td>
</tr>
<tr>
<td>Bus Interior Design (2)</td>
<td>Industrial Design</td>
<td>Conceptual rendering details of passenger &amp; driver compartments</td>
</tr>
<tr>
<td>Bus Climate Control Systems</td>
<td>IT – Vehicle Design</td>
<td>Researched passive &amp; active climate control systems for buses</td>
</tr>
<tr>
<td>Solar Energy Storage Systems (3)</td>
<td>IT – Vehicle Design</td>
<td>Detailed research of solar collector technology and preliminary roof mounted system design proposal</td>
</tr>
<tr>
<td>Hybrid Powertrain Integration</td>
<td>IT – Vehicle Design</td>
<td>Narrowed IC engine selection and developed CAD model for chassis integration</td>
</tr>
</tbody>
</table>

Assessment of the independent study activities is a bit more challenging due to the fact that some of the courses are student defined, the level of credits sought varies, as do the resultant level of
deliverables, and content coverage can vary based on the individual student focus. It has most likely been sleuthed through reading the preceding sections that the author prefers rubrics for grading whenever possible. As part of the initial independent study proposal process, a grading scheme is negotiated between advisor and student, and usually involves use of a rubric created by the author, which is modified to suit the needs and format of the individually defined courses of independent study. Through experience, it has been found that the independent study courses, and their close cousin, the capstone senior project courses, which are basically 2-quarter independent studies with separate proposal and implementation segments, tend to be the most difficult to grade due to their relatively unstructured formats. This is where the grading rubric shines; by having specific areas of focus for grading agreed upon at the start of the course, the final grade becomes less subjective, as it comes down to how effectively the student completed the pre-determined content areas. It should be noted that in addition to the (20), and counting, independent studies, there have been (2) senior project activities completed for the Hybrid Bus Project, with both focusing on thermoplastic composite materials R&D for body and chassis application.

Collaborative Approach

“Scientists and engineers work mostly in groups and less often as isolated investigators…the collaborative nature of scientific and technical work should be strongly reinforced by frequent group activity in the classroom…” This statement by Harvey and Daniels reflects the nature of most design and development activities in the automotive field. While individual engineers and scientists may be very capable of handling the technical challenges associated with their assignments, industry best practices, accounts by successful development teams, and the experience of this author concur that there is strength in the collaborative team approach. The old adage that “two heads are better than one” is illustrated in many of the automotive industry analysis and problem solving methods such as QFD, DFMEA and general design reviews, when the success of such activities relies heavily on the ability to organize multidisciplinary, or cross-functional groups. Through the collaborative approach of groups comprised of individuals with expertise in specific areas of focus, the unique perspective each member brings to the table serves to create a more robust final product, as it satisfies or addresses concerns on several fronts. An example of this in industry can come from the many product design reviews the author initiated with members representing manufacturing engineering, industrial engineering, quality engineering, finance and production. We were fortunate to have the design responsibility for the product in the same facility that manufactured components and assembled the final product. Too often the design is conceptualized in a separate facility from that which is responsible for producing it, and the outcome can suffer from the failure of not bringing together all of those with relevant previous experience, or by not addressing concerns from all areas associated with production. By addressing cross-functional group concerns up front during the early stages of product development, overall savings can be recognized through a reduced number of costly, late design changes in manufactured and supply base tooling, as well as reduced lead times for new product launch due to the lack of “surprises” faced by those involved in the earlier design reviews. By including many of the functional
areas, the overall design proves to be more robust, especially if formal discussions / analysis occurred for design for manufacturing (DFM), design for assembly (DFA), design for service (DFS), design for...X, etc.

The Hybrid Bus design concept can be much more successful by developing similar types of multi-disciplinary, collaborative teams to those used in industry. While the majority of core R&D team members are from the IT-VD program, each student brings with them their own perspectives, autobiographical experiences and skill sets which are utilized to improve the overall results. As previously stated, several core R&D team members are representatives from the composites manufacturing and transit industries, such that perspectives are included in these critical areas where the students and faculty may be deficient.

While the entire Hybrid Bus project is an example of the collaborative design approach, a specific workgroup example are the DFMEA sessions that the group is working on as of the writing of this document. The DFMEA process seeks to review intended function of subsystems and individual components, analyze potential failure modes of these systems, assign corrective action measures to assure the design is robust, and prioritize analyses and preventative measures suggested by the review group. The DFMEA process is a tool widely used in the automotive industry that was developed by the Automotive Industry Action Group (AIAG), which is comprised of the big three US based auto manufacturers (Chrysler / GM / Ford). Use of the DFMEA process on the Hybrid Bus project is a good practical application that provides the students with an understanding of the process, matrices used, and methods for making it a useful tool, as opposed to just more paperwork that needs to be completed. One mistake that was made for the initial DFMEA reviews was that we started them over the summer session when the student population is scarce and those that are in the area are seeking summer work or exploring the great Pacific Northwest. Needless to say, our multidisciplinary groups were small in numbers, yet we are confident that the results obtained will provide the basis for a strong design. We chose to focus on powertrain design and integration first, have completed body and chassis analysis and are following up with suspension systems, and interior design. Once the larger scale systems are completed, we will revisit areas that require the focused efforts associated with this process.

A sample page from the completed powertrain DFMEA analysis is provided in Figure 4. The process starts by identifying major functions or descriptions of the component or subsystem. We selected to approach the activity as a conceptual DFMEA, as opposed to a detail DFMEA, as the design is not mature, and it allows for a more macroscopic view, while still identifying critical aspects. The process starts by listing critical functions or providing descriptions of items that are potential areas of concern. For each item, single or multiple potential failure modes are then defined. Effects of the failure on the potential end user, or next-in-line customer are discussed, and severity rankings are determined by the group. Severity rankings follow a pre-determined list suggested by AIAG, with 1 being least severe and 10 being most. Potential causes of the failure are then discussed and ranked for probability of occurrence. While AIAG provides guidelines for occurrence ranking values, they are associated with high volume products; the Hybrid Bus project is targeting one initial prototype unit, with up to (200) initial production units, and the potential for 3000-4000 vehicles annually. The group
used the AIAG scale as reference; however, the associated values did not apply. Design controls were then evaluated which can consist of items such as analytical techniques, CAD modeling, dimensional analysis and development testing. The intent is to confirm or create design controls that will prevent the failure mechanisms from impacting the design. There may be areas that the design controls are not adequate enough to prevent the potential concerns from affecting the design, which would trigger a high rating. Understanding the limited resources available to this university-based R&D team, in comparison to typical dedicated industry-based teams, there are some areas that the current design process is not capable of addressing, such as high mileage testing, or simulated fatigue testing. These areas are identified and tagged for transfer to the production intent source, which should have enhanced resources, or the financial ability to address. Once the three rating values have been obtained, a risk priority number (RPN) is determined based on the product of the three ratings. Threshold RPN

Figure 4 – Sample Page from Powertrain DFMEA
values that trigger the need for recommended actions can vary by group. The Hybrid Bus R&D team determined that RPN’s greater than 90, or any severity value rated a 10, which indicates a potential occupant safety concern without failure warning, would warrant a corrective action. Recommended actions along with responsible team members and target dates are then determined. A critical aspect of the DFMEA process in relation to ISO certification deals with reaction and follow-up to the indicated corrective action items. In industry, those organizations targeting ISO certification must provide assurance that follow-up systems are in place and that items such as DFMEA corrective actions are completed in a timely fashion. The DFMEA process is one of many collaborative team approach tools that is currently used in industry and applied to the Hybrid Bus project. While there are design and development areas that often require individual effort, the team will continue to utilize the collaborative approach to provide a robust design, and to allow for the students to experience this method for inevitable use in their future careers.

Summary

The author has presented an example of how project based instruction has improved the overall ETEC curriculum effectiveness at Western Washington University. Through the interweaving of project related activities into required coursework the students are able to complete their degree requirements while simultaneously helping to achieve project goals. The nature of the Hybrid Bus project presents a very real application for the students to expand and apply their developing skills to, and allows exposure to activities that many graduates from the program will encounter as they enter their fields of employment. The merits of a project based educational approach were discussed, which included the ability to provide tangible activities for students to connect the more abstract concepts to, as well as the provision of a strong environment for the more tactile learners, to enable differentiated instruction. The supplemental nature of certain aspects of the project likewise allow for more informal educational activities which help to reinforce concepts discussed in the classroom. Additionally, the project has provided the basis for many independent study activities which allow the students to gain more in-depth knowledge in areas of interest, while building the collective knowledge of the team, and the department. The WWU VRI was built upon the foundation of such vehicle R&D projects, and will continue this approach as long as inquisitive minds and the need for improved mobility options exist.
Objectives:
- To provide the students with exposure to quality function deployment analysis, and its application to design initiation
- To obtain an understanding of the "voice of the customer" design approach, and to provide a means for establishing design
- To expand on the concept of quality of design, and link the activity results to practical examples

Set-up and Procedures:

1) Split up into groups of 4-6, and assign the following roles (where applicable):
   - **Design Engineer** - establishes matrix; checks design feasibility
   - **Administrative / Management Level Customer** - concerned with "macro" use; fleet operation; long term economics; maintenance
   - **Operator Level Customer** - concerned with delivering product to end user; consumer interface
   - **End Consumer** - end use customer

2) Determine a product or sub-system to conduct a QFD analysis on. Suitable products should consist of more complex systems to allow for a range of customer levels and/or a range of potential desirable functions / features. For example, a pencil is too simple in function, features and target customer, but products like a cellular phone, scooter or downhill ski set are sufficiently complex in these areas, to provide the basis for a worthwhile analysis.

3) Review the sample QFD matrix provided, and establish a similar matrix in MS Excel for your group, that will provide a minimum of (4) desired features for each customer type, and 1-2 potential design solutions for each customer requirement.
4) Reference the QFD Process outline sheet, and complete the following:
   a) Customer requirements
   b) Engineering priority ranking (1-5)
   c) Customer priority ranking (1-5)
   d) Design solutions
   e) Rank design solution strength (0, 1, 3, 9)
   f) Benchmark analysis
   g) Determine technical importance (\( S = [\text{relationship value} \times \text{customer importance}] \))
   h) Rank the technical difficulty (1-5)
   i) Establish correlation matrix
   j) Establish objective design targets
   k) Determine critical focus areas

** The completed matrix should be shared amongst the group

5) Provide a summary of the group's activity and indicate the critical items targeted for your new design.

6) Complete an individual Lab write-up, with the following general areas included:
   - Lab Title
   - Lab Overall Objective(s)
   - Summary (include comments on value of this activity and how to improve future Labs)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>0 POINTS</th>
<th>5 POINTS</th>
<th>10 POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Write-up Structure</td>
<td>Missing &gt; 2 of any of the items in step #6 above</td>
<td>Missing 1 of any of the items in step #6 above</td>
<td>All of the items in step #6 above are addressed</td>
</tr>
<tr>
<td>Content</td>
<td>Overall write-up is weak; discussion / conclusions are insufficient or unrelated; no value comments in summary</td>
<td>Overall write-up is fair; discussion / conclusions are moderately related; few value comments in summary</td>
<td>Overall write-up is strong; discussion / conclusions are clear, concise &amp; related to topic; meaningful value comments included in summary</td>
</tr>
<tr>
<td>QFD Activity</td>
<td>Missing &gt; 2 critical items from step 4; no analysis of process &amp; results</td>
<td>Missing &lt; 2 critical items from step 4; fair analysis of process &amp; results</td>
<td>No missing items from step 4; thorough analysis of process &amp; results</td>
</tr>
<tr>
<td>Lab Activity Participation</td>
<td>Individual contribution non-existent; did not participate in group activity; worked on non - ETEC-344 activities in Lab</td>
<td>Individual contribution &lt; other team members; mediocre participation in group activity; on task &gt; 70% but &lt; 80% of time</td>
<td>Individual contribution = other team members; full participation in group activity; on task &gt; 80% of time</td>
</tr>
</tbody>
</table>
1 Based on Safety Committee Study from Central Square Central School District, Central Square, NY (circa 2005)