ABSTRACT

Today's automotive and electronics technologies are evolving so rapidly that educators and industry are both challenged to re-educate the technological workforce in the new area before they are replaced with yet another generation. In early November 2009 Ford's Product Development senior management formally approved a proposal by the University of Detroit Mercy to transform 125 of Ford's “IC Engine Automotive Engineers” into “Advanced Electric Vehicle Automotive Engineers.” Two months later, the first course of the Advanced Electric Vehicle Program began in Dearborn.

UDM's response to Ford's needs (and those of other OEM's and suppliers) was not only at the rate of “academic light speed,” but it involved direct collaboration of Ford's electric vehicle leaders and subject matter experts and the UDM AEV Program faculty. In fact, before teaching each course, the UDM engineering and science professors will work for one or two months in the Ford engineering group that is directly involved in the design and development of the systems that the course focuses on (batteries, e-drive systems, power electronics, etc). The prime architects of this process and curriculum include the UDM dean, associate dean and faculty of engineering and science from UDM, and Ford Learning & Development managers and Product Development leaders from Sustainable Mobility Technologies and Research & Advanced organizations.

Such a rapid and highly responsive curriculum development is not the norm in academia. To accomplish this outcome UDM had to be more customer-focused like industry and Ford needed to embrace academic priorities and provide access to its electric vehicle SME's by UDM faculty.

The paper will discuss the following related issues: building the relationship and trust between Ford and UDM; collaborative development; “just in time” development and deployment of curriculum; shared investment; modularizing education (it doesn't always have to be in “degree-sized chunks”), linking suppliers and OEMs; balancing service to corporations and service to students.

INTRODUCTION

“All we want is a cohesive educational program that includes the latest knowledge that is most relevant to my job that's delivered in a convenient way by exceptional teachers.”

- the working engineer

“All we want is an educational program that infuses those unique competencies and technologies into our engineering team such that our strategic goals and product plans are efficiently accomplished with high quality ... but we can't really tell you too much about our strategic goals nor product plans.”

- the corporation
“All we want to do is to provide exceptional graduate education that provides longstanding value to our graduates by developing deep sustainable competencies ... not just technology training that fades in value as the technology changes.”

- the university

That sounds simple enough. Create curriculum that meets the needs of fast changing industry needs to be competitive, retrain the workforce and infuse new methods, concepts and technologies.

The discussion of the relevance of engineering education and its service to industry is not a new issue. Here are four quotes from studies of engineering education within the last decade:

- “In an era of unprecedented technological advancement, engineering practice continues to evolve but engineering education has not changed appreciably since the 1950s.”[1]
- “When we walk into an arbitrarily chosen engineering classroom in 2000, what do we see? Too often the same thing we would have seen in 1970, or 1940. The professor stands at the front of the room, copying a derivation from his notes onto the board and repeating aloud what he writes.”[2]
- “But we must ask if it serves the nation well to permit the engineering profession and engineering education to lag technology and society, especially as technological change occurs at a faster and faster pace. Rather, should the engineering profession anticipate needed advances and prepare for a future where it will provide more benefit to humankind? Likewise, should engineering education evolve to do the same?”[3]
- Challenges for lifelong learning in engineering could be summarized as “faculty won't play & industry won't pay”[4]

Over the last decade there have been a series of studies that led to calls for recasting engineering education such that it is more effective in terms of such areas as design[5, 6], product development[7, 8], manufacturing and quality[9, 10] and innovation[11]. Many national initiatives have been undertaken to respond to those calls, including ABET 2000[12], the NSF Engineering Education Coalitions[13,14] and Engineering Teaching Centers[15]. Most of these have focused on new pedagogical methods and the development of faculty members' teaching competence, not on how industry leaders and faculty member (how corporations and universities) can effectively collaborate.

One key aspect of making graduate engineering education relevant is the speed with which it is developed and revised to incorporate emerging technologies that are ready for commercialization and to create new products that are desired by customers and/or needed by society. The field of advanced electric vehicles is quintessential as a confluence of time driven factors. Society is concerned about the impact of burning fossil fuels on our environment, both locally and globally, and the nation's dependence on the dwindling supply of oil, especially from foreign sources. While these issues make advanced electric vehicle desirable, the lack of scale and robustness of technologies have not made them economically competitive with internal combustion engines. Technological advancement in key areas, especially batteries and “smart grids”, will be needed to overcome cost disadvantages and power distribution challenges. As such, AEV engineering and education must both develop and guide the emergence of key technologies and systems to be effective and they must evolve and respond as those technologies become more commercially viable.

Thus, AEV engineering education programs must be created not only from traditional academic knowledge sources, such as journal papers from university and government laboratory sources, but also from less traditional sources, such as the lead engineers in companies that are driving those technologies forward. However, the access to those lead engineers (or “subject matter experts”) is limited by the degree to which their employers allow them to openly discuss the emerging technologies and products and technology trajectories with university faculty.

There are also barriers to this ideal partnership in most universities. The “academic freedom” of individual faculty member in teaching their courses can work against having a cohesive program where the whole (program) is much more valuable than sum of the individual parts (courses). Also, academic governance processes can be so time consuming and cumbersome that a new program can take a year or more to be approved by departmental, college and university level committees. Further, the sense of some faculty members that “we are the experts” with the deep knowledge, and the engineers working in industry are not, can lead faculty members to disregard or devalue the input of very competent engineering leaders, many of whom have graduate degrees including doctorates, and regularly develop graduate level R&D findings from their work. If such lack of cohesion, respect and timely delivery are not dealt with effectively, the ultimate value of the resulting programs is severely compromised.

Today's automotive and electronics technologies are evolving so rapidly that educators and industry are both challenged to re-educate the technological workforce in the new area before it is replaced with yet another generation. State and federal government agencies also recognize the importance of AEV technology and the impact to job creation and retention. As such, the speed with which commitments are made, curriculum is developed and students are recruited or selected are all critical to assuring that students learn the very latest and most relevant technologies. In order to address the fast changing needs and to overcome the barriers described in this
UDM and Ford responded with a unique partnership that is described in the next section.

**Establishing the partnership**

The ideal first step in overcoming these barriers to an effective partnership is to establish a high level of mutual respect and trust. Between the Ford engineering community and the UDM College of Engineering and Science, that step was accomplished many years ago. Since the early 1900's, the university has been a significant source of engineering talent for Ford. In the past two decades, UDM has developed and delivered several programs that were specifically designed to provide key competencies for Ford employers. These included on-site Bachelors degree programs in mechanical engineering, manufacturing engineering and computer science, all containing customized cases and projects based on deep dialogue with Ford's engineering leadership. Later in the 90's, UDM partnered with Ford and other leading international corporations and MIT to provide the Masters of Science in Product Development to engineers at Ford and Detroit-based companies. These experiences demonstrated UDM's effectiveness in creating curriculum that was responsive to the specific needs of Ford, and developed in Ford the trust needed to be open in conveying both the current and desired state of their engineering capabilities to UDM. The longstanding success of those education programs also developed UDM's trust that Ford's guidance was not focused on short-term needs that would not justify the level of effort needed to develop such responsive curriculum.

Furthermore, both UDM and Ford are actively participating in a Michigan Department of Energy, Labor & Economic Growth's sectoral skill alliance, the Michigan Academy for Green Mobility, whose mission is to provide rapid skill growth in green technology solutions for advanced mobility to meet industry needs. The MAGM is a group of automotive manufacturing employers, education and training providers, industry associations, and the workforce system working to develop a mechanism for providing that training. Such participation ensures alignment with the industry's view of AEV training and educational priorities.

Even with the long history of effective partnership and the MAGM participation, the following important steps were needed to assure that the curriculum would be on target and on time:

**Step 1.** Define the target audience: what engineers would be taking the curriculum? What will be their roles and responsibilities in developing world class advanced electric vehicles (AEVs)? It was decided that this program would educate the AEV application engineers who are expected to directly contribute to the design and analysis of Advanced Electric Vehicles. (These are not the core experts in the essential subsystems of AEV, such as batteries or electric drive motors who require far more depth that might be provided by single courses in their areas.)

**Step 2.** Define the competencies required to perform those responsibilities: This step involved extensive meetings and dialogue between leaders from Ford and UDM.

**Step 3.** Define the learning outcomes for the courses and curriculum that will build those competencies: The entire team of instructors was defined early in this process and that team defined a cohesive curriculum. The syllabus for each course, including learning outcomes, was drafted and reviewed by technical leaders from Ford. [Timeline : Steps 1 - 3 were developed between April and August 2010 when key electric vehicle engineering leaders and Learning & Development leaders from Ford engaged in extensive discussion with UDM faculty and administration. This defined the program structure and course descriptions. Teams from Ford and UDM also visited the University of Wisconsin and Pennsylvania State University to learn from their programs and explore possible collaboration with their programs.]

**Step 4.** Shared Investment: Before further progress could occur UDM and Ford needed to commit the resources to develop the curriculum and laboratories, and the enrollments to justify that development of the program. This was done in November 2009 by both UDM and Ford making formal commitments to provide the financial support and the time of their people to develop the curriculum. Ford senior Product Development leadership also committed to sending 125 of their employees through the program over a five year period.

**Step 5.** Link UDM instructors with Ford subject matter experts (SMEs): For each of the seven courses in the program, the instructor(s) were introduced to the technical leaders at Ford who were the most knowledgeable and responsible for the subject areas. In early 2010 preliminary meetings better defined the processes and challenges in developing the related AEV systems, and the appropriate work area for instructor assignment at Ford (Step 7).
Step 6. Negotiate and execute Intellectual Property Agreement: An intellectual property agreement was necessary to protect Ford from the dissemination of confidential technology or product plans. This agreement also protected the intellectual property of the faculty members and UDM with regard to their previously developed curriculum in the fundamental areas upon which the AEV curriculum was developed. This agreement was finalized and executed during the first quarter of 2010, before the first UDM instructors began step 7.

Step 7. Imbed UDM instructors in Ford AEV teams: Each UDM instructor worked four to six weeks directly in the related AEV team at Ford. The intellectual property agreement allowed an open discussion of all challenges and developments of Ford’s AEV program, assuring that the instructors were fully aware of how various technologies and methods of design and analysis were employed in AEV development at Ford. These periods are occurring during the spring and summer terms of 2010, before or during the first offering of each course, depending on the “off-term” of each faculty member.

Step 8. Develop complete courseware for each course: This step includes creation of presentation materials, projects and assignments. Per the intellectual property agreement, AEV leaders at Ford reviewed all materials that incorporated any information learned at Ford to assure that it did not include confidential information. This also allowed those leaders to comment on the content and suggest improvements.

Step 9. Deliver the curriculum: The first AEV Certificate Program cohort of forty-five students (including 30 Ford engineers) is taking all courses at the Ford Training and Development Center in Dearborn. The first course, Introduction to Advanced Electric Vehicles, began in January 2010. Six UDM faculty members and administrators attended part or all of this course to assure that subsequent course built off of the content of this first course. The remaining six

<table>
<thead>
<tr>
<th>Course Subject Area</th>
<th>UDM Instructor(s)</th>
<th>Ford SME(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Electronics</td>
<td>Professor, Electrical Engineering. Over 25 years of experience in teaching in this area.</td>
<td>Senior Tech Leader – Electric Machines, Senior Tech Leader – Electrical Hardware/Systems</td>
</tr>
<tr>
<td>Controls in AEVs</td>
<td>Assistant Professor, Mechanical Engineering. Expert in linear, non-linear and discrete controls.</td>
<td>Technical Leader – Vehicle Controls, Supervisor – HEV Powetrain Controls</td>
</tr>
<tr>
<td>Electronic Drives</td>
<td>Professor, Mechanical Engineering. Over 15 years of teaching experience in areas including mechatronic systems.</td>
<td>Senior Tech Leader – Electric Machines</td>
</tr>
<tr>
<td>Batteries</td>
<td>Professor, Chemistry and Professor, Mechanical Engineering. Both with more than 15 years of teaching experience and several awards for teaching.</td>
<td>Senior Manager – Energy Storage &amp; Research, Senior Engineer – HV Battery</td>
</tr>
<tr>
<td>Innovation and System Architecture of AEVs</td>
<td>Assistant Professor, Mechanical Engineering. With more than 25 years of industrial experience in product development.</td>
<td>Technical Leader – Concept Analysis &amp; MBSE, Technical Expert – HEV Powetrain Calibration</td>
</tr>
</tbody>
</table>
courses of the AEV Certificate Program are being delivered in the Summer and Fall terms of the 2010 calendar year.

**Step 10. Develop laboratory experiences and equipment:**
Laboratory experiences were designed for three courses, E-drive, Power Electronics and Control of AEV’s, to be delivered at UDM’s campus on Saturdays. The laboratory stations were derived directly from the stations designed by an NSF funded team at the University of Minnesota led by Dr. Ned Mohan. Three UDM faculty and administrators attended an NSF Workshop on teaching power electronics to learn the methods and materials created by Dr. Mohan's team. During the first four months of 2010 the laboratory renovations were made and laboratory equipment was purchased and set up allowing the first labs to be offered in the summer of 2010.

**A Unique Process of Curriculum Development**
The curriculum development process implemented in this program is somewhat different from traditional approaches typically followed in academia. Characteristics of this approach include speed of development, just-in-time deployment, involvement of industry experts at different levels, integration of knowledge from different sources such as texts, publications, national labs, other university courses, close cooperation and coordination among all the faculty members involved, etc.

**Involvement of Industrial experts**
Curriculum development was done in close co-operation with Ford technical leaders at different stages. The course areas and target audiences were determined through consultation with Ford technical leaders in different areas of expertise such as electric vehicle product development, research, energy storage devices, vehicle and power train control, systems engineering, etc. UDM's faculty development team and the industry team met to jointly determine the programs key areas of focus and the areas of proprietary knowledge that would be more appropriate for Ford internal training programs. This analysis and collaboration allowed for better definition of target audience, program objectives and outcomes, titles of the courses to be taught, and the required courses and electives. The AEV program was crafted to complement, not compete with, the Ford internal training strategy resulting in more efficient and tailored learning options for working engineers. Also, UDM and Ford's involvement in the Michigan Academy for Green Mobility provides insight to an industry wide perspective on key competencies, skills and learning objectives as a guide and reference.

The AEV program objectives were determined to be:
- To educate engineers in the principles and performance of Electric and Hybrid Electric Vehicles, including its components, sub-systems and their interaction, power generation, storage, control aspects and system integration.
- To educate engineers who excel in the professional practice of innovating, designing and building Advanced Electric and Hybrid Electric Vehicles. This will include the ability to identify, design and implement innovative solutions to technical problems associated with AEV systems.
- To educate engineers to be aware of how their roles as technical professionals change with the change of vehicular technology from gasoline driven to electric and hybrid electric vehicles.

And the learning outcomes are:

Students completing this certificate program will have the ability to:

a). apply knowledge of AEV vehicles to solve problems in AEV design and system integration.

b). design, develop and use validated system models for AEV components and systems to solve problems associated with AEVs.

c). design and develop optimum power storage solutions by designing and developing battery systems. This includes all aspects of power storage such as battery chemistry, packaging and layout design, thermal management, manufacturing and charging process and life-cycle management.

d). choose and integrate proper E-drives for vehicle powertrain and other applications associated with AEVs.

e). implement proper electronic solutions for power conversion and management problems associated with AEVs.

f). implement optimum solutions for control problems associated with AEV systems.

g). analyze as well as design an optimum architecture for AEVs systems.

h). function effectively on multi-disciplinary teams and interface effectively with engineers developing the AEV.

The technical competency areas that are going to be targeted through new courses were also determined and outlines of seven courses were developed. Of the seven areas three courses were to be taken by everyone enrolled in the program. These three courses are:

- **AEV 5010:** Introduction to Advanced Electric Vehicles
- **AEV 5020:** Controls Modeling and Design for AEV
- **AEV 5050:** Electric Drives/Electromechanical Energy Conversion
It was also determined that two out of the following four courses would be taken as electives. With these specific four courses individuals would potentially have a choice between a technical track (with courses AEV 5030 and 5040) or a systems/innovation track (with courses AEV 5060 and 5070).

- **AEV 5030: Energy Storage Systems**
- **AEV 5040: Power Electronics for Electric Vehicles**
- **AEV 5060: Innovation and Systems Architecture for AEVs**
- **AEV 5070: Systems Engineering for AEVs**

The interaction with industry experts did not end at this stage. The instructors of each of the above courses were then linked to one or two industry experts in their area. These individuals went over the course outcomes, list of topics, level of coverage, prerequisites, etc for their course before finalizing the content. Also, each instructor spent about a month in the organization of their Ford counterpart learning how important technical issues are handled within Ford. The plan was to develop a case study that can then be taken to the classroom for teaching important concepts.

“Just in time” development and deployment of curriculum

While discussions about the program with Ford leaders started in the summer of 2009 the program did not get approved until November 2009 and the first class was to start in January 2010 followed by three classes in summer 2010 and three more in fall 2010. Given that none of these courses except the introductory course in the proposed form existed in the UDM curriculum, this was an exemplary “just in time” development, deployment and delivery of the curriculum. All the other courses were developed as the program took shape. The university process to approve the certificate program was initiated as soon as Ford approved AEV courses. This process went on for several months and concluded in March, 2010. By that time the first course was well under way. Instructors started work on their courses as soon as the program was approved. This included development of the outline, meeting and working with industry counterparts, development of course materials, laboratory development, etc. In traditional University courses changes usually happen incrementally and much more slowly. But in this case the whole curriculum of seven courses was developed in less than one year.

Another unique and “fast-to-market” course development approach used was the creation of 4-hour short courses to “test” course content and get immediate feedback from industry engineers. UDM and Ford Learning & Development partnered to offer several short course sessions based on the AEV curriculum for hundreds of Ford engineers. The short courses are taught by UDM professors on site at Ford training facilities and include student surveys created to provide rapid feedback from engineers already working on advanced electric vehicles. This type of feedback would usually take a year or more to gather in a normal graduate course survey process, but is now provided within days or weeks. Another benefit of these short courses is that they provide more rapid infusion of AEV knowledge within Ford and offers UDM broader exposure of the AEV certificate program to prospective students.

Expansion of faculty expertise

For faculty members who offer new courses in areas that involve the application of their expertise to a new area, the process is usually slow. This process often involves learning of the material through research experience, interaction with other experts, reading of relevant literature, etc. In order to meet the needs of this program, special steps were taken to expedite this process for all the faculty teaching in this program. We have already talked about the interaction between faculty and the experts from industry. Apart from that faculty attended courses and workshops to enhance their understanding of Electric Vehicle technology. Some of these workshops and courses include:

- **Workshop on Electrical Energy Systems-Education and Research, Tucson, AZ, Feb 2010**
- **Short course Introduction to Hybrid and Electric Vehicle Battery Systems, Society of Automotive Engineers, April 15-16, 2010**
- **Visits to National research labs such as Argonne National Labs, etc.**
- **Discussion with experts from the Defense sector at Army Tank command (TARDEC)**

The unique outcome

The outcome of this effort is the program's innovative structure, flexible in design so that both industry and academia requirements are fully met, and rich in relevant pedagogy and content. The next few paragraphs discuss these features of the final outcome.

Program Structure

During initial discussions about the program the details of the program was not clear but it was agreed that the curriculum will have to be at the graduate (Master's) level. Through the discussion it was determined that the number of courses will not be enough for a traditional Master's degree program and that many engineers in the target audience already had advanced engineering degrees and may not want nor value another full degree program. So it was decided that a certificate program for AEV will be developed. In order to complete the program the students will need to take five courses and they can complete this coursework in a year's time. Of the five courses three were compulsory, addressing
the core competencies their employers expect them to have and two electives. The electives were chosen in a way such that the students can choose a deep technical track or a systems track. The one-year certificate program is more than just a list of courses that the students take; the length of time is just right so that the student is neither overwhelmed nor do they feel that the end-point is very far off. Also, the certificate at the end of the program (although not a degree) is something tangible to give them a sense of achievement.

At the completion of the certificate program the students can continue on to one of four Master's programs: Master of Product Development, Master of Engineering in Mechanical Engineering, Master of Electrical Engineering, or Master of Engineering Management. In all of these programs at least four of the five courses will transfer. The availability of this transfer opportunity is encouraging a number of students in the certificate program to think about subsequent enrolling in a Master's degree program.

The program is now being offered at multiple sites starting one semester later than the first cohort. This not only caters to a larger number of students but will also provide the option for students to take classes at either of the two locations. The course sequence for the first offering is shown here. This sequence is going to be repeated for other cohorts.

Pedagogy: strong cases, projects, integrated labs; distance learning
The pedagogical approach is a combination of strong theoretical foundations supplemented with modeling and simulation to enhance the understanding of complex concepts, laboratory activities to provide hands-on experience, and case studies developed with help from industry experts to contextualize the topics. As described before the topics in each of the courses are selected carefully and are presented in a traditional lecture format in the class. Simulations used as demonstrations as well as simulation-based exercises are used as necessary to supplement the lecture content. Hands-on laboratory activities are used to teach concepts with real data.

Once all the courses are taught one time the program will also be implemented as an on-line program as well. This way, students who are physically far away from southeastern Michigan can learn from these classes by enrolling in the on-line version of the certificate program.

Content: not your standard power electronics (or controls, or systems engr. or … .) course, but customized
As was mentioned before while some of the technical and theoretical content came from other courses, none of the courses existed in the curriculum in their current form. All the topics were reviewed for their relevancy for the program and were included or discarded based on this relevancy review. Also, topics that are otherwise generic in nature are customized to reflect their relevance to the Electric vehicles. In the next few paragraphs we have highlighted this with some specific examples.
Energy storage components such as batteries are a vital piece of the electric vehicle development and a number of physical phenomena are involved in battery operations.

These include the chemistry, thermal management, electrical management, weight optimization, packaging, and systems integration. This is a very non-traditional topic in university courses and electric energy storage is not a commonly available course in any curriculum. Due to the emergence of alternative energy technology, modernization of electric grids and advent of electric vehicles in the commercial market, batteries and storage technology has become an issue of importance. UDM's course on battery will be team taught by a chemistry professor as well as a mechanical engineering professor in order teach all the aspects well. An industry expert on battery design and development is also part of this team and will teach a few special topics on energy storage.

A traditional electric machines course is quite different from the electric drives class that is offered as part of this program. In a traditional electric machines class transformers, DC machines and AC synchronous as well as AC induction machines and covered in extensive detail. In the electric drives course the topic of transformers was completely discarded. Also, between the different types of AC machines AC synchronous machines, particularly those with permanent magnets in their rotors is emphasized since that is the type that is predominantly used in electric vehicle applications. Along with this some aspects of motor sizing based on vehicle performance requirements, as well as some topics of power electronics are also discussed in this class. These topics are not part of a traditional electric machines class.

Any controls class or a sequence of controls courses that is available in a typical university curriculum are very general and mathematical in nature. They delve deep into the theory of controls, different approaches of control algorithm design, their stability issues, etc. While these are all important topics, the practicing engineers need to know more about the control of actual electric vehicles, their drive trains, etc. So the controls course in this program is being specially designed to address these issues. A lot of the deep mathematical analysis will be replaced by simulation based learning of controls problem as applied to the power generation and distribution in electric and hybrid electric vehicles as well as the controlling of the vehicles themselves.

CONCLUSION - LESSONS LEARNED

The AEV team from the University of Detroit and Ford Motor Company has executed a rapid process of intensive collaboration to create a unique program that is directly responsive to mutually defined objectives and learning outcomes. Also, UDM and Ford's involvement in the Michigan Academy for Green Mobility provided insight to an industry wide perspective as a guide and positions the AEV certificate program for MAGM endorsement without further development or investment.

Classes are underway for this program in this first year and a lot of valuable lessons are being learned during the first offerings. These lessons relate to relevancy, content, mode of presentation, balance between modes of instructions such as lecture, laboratory exercises, team projects, and simulation based-learning, work-life-school balance, etc.

The lessons learned from the first offerings will enable the faculty-industry partners to tune the curriculum for future offerings.

This project may provide insights and inspirations for other industry-university partners to engage in similar initiatives that can quickly infuse deep knowledge of critical emerging technologies into America's engineering workforce.

REFERENCES


CONTACT INFORMATION

Shuvra Das, Associate Dean
College of Engineering and Science
University of Detroit Mercy
313-993-3380
dass@udmercy.edu

Leo E. Hanifin, Dean
College of Engineering and Science
University of Detroit Mercy
313-993-1216
hanifinl@udmercy.edu

Sean M. Newell, Dean
College of Product Development
Quality and Manufacturing Engineering
Ford Learning and Development
Ford Motor Company
313-805-4137
snewell1@ford.com