# Chapter 25

# Implementing an Integrated Learning System for Hybrid Vehicle Technology: Supporting the Green Transportation

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*World competition and stringent United States fuel economy goals, and emission regulations for the 21st Century vehicles, have pressured the automotive industry to design and evaluate advanced automobiles at an accelerated rate. The industry consensus is that the Hybrid Electric Vehicle (HEV) represents the currently available technology for increasing propulsion system efficiency and decreasing pollutant emissions. However, HEVs operate much differently than conventional vehicles. Therefore, existing design techniques and guidelines developed for conventional powertrains do not apply well to hybrid vehicles. There is a need for training automotive technicians and engineers as well as educating students in this new and emergent technology of HEV. This paper describes a funded project whose goal is to fill this need by developing integrated learning system for HEV technology. This project targets engineering/engineering technology students in 4-year universities, automotive technology students in community colleges, automotive engineers and technicians in industries, and technology teachers in secondary schools.*

## INTRODUCTION

U.S. oil imports, which include both crude oil and petroleum products, are predicted to rise to 16.4 million barrels per day by the year 2030 [1]. This need for oil affects our national security. Also, vehicle emissions are the leading source of U.S. air pollution, which jeopardizes the health of citizens. In the era of rising environmental sensibility and limited, even depleting supplies of fossil fuel, the development of a new environmentally friendly generation of vehicles becomes a necessity. Hybrid electric vehicles (HEV), which combine an electric drivetrain with an internal combustion engine (ICE) or fuel cell, are one means of increasing propulsion system efficiency and decreasing pollutant emissions [2-5]. Hybrid powertrain systems allow for significant fuel economy enhancements over conventional powertrain systems by: (a) Allowing the engine to be turned off when idling or during periods of low power output – two highly inefficient stages of typical engine operation; (b) Allowing for a downsized engine and consequent higher average engine efficiency operating for a specific set of vehicle/powertrain performance requirements; (c) Providing launch assist; (d) Providing regenerative braking energy recapture; and (e) Supplying assist during varying power demand. The expected marginal return of each additional mile per gallon in terms of fuel efficiency will significantly reduce the level of greenhouse gasses emitted via automobiles, thus slowing the rate of global warming and reducing the rate of world pollution.

Hybrid vehicles use an upgraded propulsion system in which energy is used more efficiently than in standard systems. A standard propulsion system has four primary components: (a) The internal combustion engine to supply power for the other vehicle systems; (b) The transmission to control the speed ratio and the level of torque multiplication between the engine and the final drive; (c) The final drive and drive axle assembly to multiply transmission output torque and transfer power to the wheel assembly; and (d) The tire and wheel assembly that transfers power from the axle assembly to the ground. To hybridize a vehicle propulsion system, electric machines must be connected somewhere in the power flow.

Based on the ratio of electric power to total power of a vehicle, the degree of powertrain hybridization is typically classified into two levels: mild and strong (or full) hybrids. The mild hybrid propulsion systems include Belt Alternator Starter (BAS) [6-8] and Flywheel Alternator Starter (FAS) or Integrated Motor Assist (IMA) [9-10]. The strong hybrid propulsion systems include strong FAS (or IMA) [11-12] and Electrical Variable Transmission (EVT) [13-14]. The above systems are commercially available in today's market, such as Saturn Vue hybrid (BAS), Chevrolet Silverado hybrid truck (mild FAS), Honda Insight, Civic and Accord hybrid (strong FAS), Ford Escape Hybrid and Toyota Prius (single mode EVT) and Chevrolet Tahoe hybrid (dual-mode EVT).

The hybrid vehicle first reached the market in 1999 and has become increasingly popular, with more than 340,000 sold in the United States in 2007. The development of power sources for hybrid vehicles has rapidly increased in recent years, the configuration of which is distinctly different from traditional vehicles. At present fourteen hybrid vehicle models are on the road in the U.S. and sales are projected to increase as the range of choices grows: 65 hybrid models - 28 cars and 37 light trucks - in the market by 2010, with sales expected to reach nearly 775,000 units, according to J.D. Power Automotive Forecasting [15]. The steadily increasing production of HEVs by the automotive industry coupled with the specialized set of skills required to accommodate the vehicles' hybrid power configuration, has created a demand for more knowledgeable hybrid powertrain engineers and technicians.

In response to the emerging area of HEV, several research collaborations between universities, automotive manufacturers, and government agencies have been formed [16-23]. However, neither systematic courses nor degree programs have been developed to train engineers and automotive technicians in the emerging technology of HEV. To date, no automotive technician program in HEV has been developed for the community college level. The required education includes safety, regulations, control systems, propulsion systems, diagnosis and maintenance. Currently automobile manufacturers are training their HEV engineers and technicians entirely "in-house," which raises the cost of producing HEVs for automotive manufacturers, and ultimately limits the number of automotive engineers and technicians available for the growing hybrid vehicle market. There are potentially 19,100 automotive service technicians in Southeast Michigan that will need some education to service HEVs to meet consumer expectations [24]. There is a clear need for a systematic training program on hybrid vehicle technology. It is not necessary to establish a new degree program in the HEV; however it is essential to integrate the HEV courses and laboratory experiments into the existing automotive/vehicle engineering curricula. An integrated or progressive learning system is proved to be the most effective approach for professional development [25-26].

This paper describes a funded project that addresses the critical need for HEV trained automotive engineers and technicians that currently exists, and will continue to grow, by creating a curricular program to train automotive engineers and technicians for work specific to HEVs. This project targets engineering/engineering technology students in 4-year universities, automotive technology students in community colleges, automotive engineers and technicians in industries, and K-12 technology teachers.

## OBJECTIVES OF HEV LEARNING SYSTEM

In order to develop an integrated HEV learning system, a partnership has been formed between faculty of the engineering technology program at Wayne State University (WSU) and Macomb Community College (MCC) automotive technology program. The partnership also includes industrial partners from major automobile manufacturers and suppliers. The intent of this project is to develop collective effort, among educators, industry, and government agency, to make positive, continual, and lasting contribution for education on the emerging technology for green transportation.

This project aims to develop an industry-based learning system for HEV automotive engineers, engineering technologists, service technicians and K-12 technology teachers. The main objective stemming from this goal is to address the critical need for training automotive engineers and technicians and educating students in this new and emergent technology of HEV. To enable us to make a positive, continual, and lasting contribution to the HEV education, we specifically set the following objectives for the project:

- Prepare students and returning engineers/technicians to be skilled HEV professionals
- Enable students to acquire industry-based experience in HEV technology through a hands-on laboratory environment
- Expose HEV technology to K-12 teachers, corporate partners, and automotive professionals
- Initiate a pilot program for Automotive Service Excellence (ASE) certification in hybrid vehicles
- Prepare community college students in Associate of Applied Science (AAS) programs to successfully transfer to the WSU's Engineering Technology program to earn a Bachelor of Science and Engineering Technology degree.

## LEARNING SYSTEM IMPLEMENTATION

Leveraging the strengths of each institution – the WSU's experience in engineering research and producing talented bachelor, master and doctoral level graduates and the MCC's reputation for innovation and educating highly-qualified automotive technicians – and pooling their respective resources (i.e., their programs, faculty, facilities, location, and industry ties), a series of activities were held to realize the stated objectives. They were as follows:

- Created an advisory committee to oversee the program
- Integrated HEV curriculum with existing AAS program in Automotive Technology
- Revised existing courses, developed HEV specific courses, and delivered these courses
- Developed and delivered a two-day short course
- Developed and delivered seminars and workshops
- Created an HEV specialized laboratory
- Created internship and co-op opportunities, plant visits, and an expert lecturer series
- Developed framework that will be used for ASE certification
- Provided transfer student advising by university faculty at community college

### Advisory Committee

Initiating the development and implementation of all activities requires a system of coordination for exchange of information and resources and effective utilization of institutional strengths. Collaboration among faculty and administrators from both institutions and their industry partners was formalized through the creation of an advisory committee, which meets regularly to develop and implement the planned activities and monitor progress of the project. To create this advisory committee, both institutions extend their existing collaborative partnership between their faculties to incorporate industry partners.

### Curriculum Integration

The current automotive service program at MCC has 500 students. The existing program is traditional and teaches students the eight bodies of knowledge required for ASE Master Certification. The primary objective is to prepare students and working technicians to be skilled HEV technicians. To achieve this objective, the MCC in collaboration with WSU and its industry partners integrated HEV education courses into the Associate of Applied Science curriculum in Automotive Technology.

The HEV curriculum is shown in Table 1. The structured curriculum is divided into three sequential sections: Automotive Fundamentals, Hybrid Vehicle Fundamentals, and Automotive Intermediate. Section I, Automotive Fundamentals, consists of basic courses of critical importance to automotive systems in areas matching the HEV focus area. A student completes this section by completing the four required courses for 11 credit hours. All courses are offered by the community college and are currently enrolling students.

Section II, Hybrid Vehicle Technology, requires two new courses that are developed as part of this project. Together there are total six credit hours, covering fundamental knowledge in hybrid vehicle technology. Students must take both Section I and II (for a total of seventeen credit hours) to complete the HEV training program.

Section III, Automotive Intermediate, consists of four optional courses that students may select to strengthen their knowledge in specific areas. Since HEVs contain both an internal combustion engine and an electrical motor using high-voltage (300 Volts), safety has been a primary concern for all who work on hybrid vehicles. A work place safety course was included as an optional course for all HEV students.

| | Section I: Automotive Fundamentals | |
|---|---|---|
| Course No. | Course Title | Credit Hours |
| AUTO 1000 | Automotive Systems | 3 |
| AUTO 1030 | Automotives Electronics | 3 |
| AUTO 1200 | Automotive Engines | 3 |
| AUTO 2410 | Advanced Automotive Electronics | 2 |
| | Section II: Hybrid Vehicle Technology | |
| Course No. | Course Title | Credit Hours |
| new | Hybrid Vehicle Fundamentals | 3 |
| new | Hybrid Powertrain and Control | 3 |
| | Section III: Automotive Intermediate (Additional Optional Courses) | |
| Course No. | Course Title | Credit Hours |
| AUTO 1100 | Automotive Brake Systems | 3 |
| AUTO 1320 | Automotive Transmission Theory and Diagnosis | 2 |
| AUTO 1400 | Automotive Starting and Charging Systems | 2 |
| PHED 2070 | Wellness – Focus prevention, intervention, treatment of disease, illness, injury. | 3 |

TABLE 1
CURRICULUM FOR HEV TECHNOLOGY

### Course Development and Revision

To integrate the HEV curriculum into the Automotive Technology Program, one existing course is revised and two new courses in HEV Technology are developed. For Section I of the curriculum, AUTO-1000 *Automotive Systems* is revised to include HEV technology in the automotive system overview. The revised *Automotive Systems* course is required for all AAS students in the Automotive Technology program at MCC. The two new courses that form the requirements for Section II of the curriculum are *Hybrid Vehicles Fundamentals* and *Hybrid Powertrain and Control.* These two courses target current students as well as returning or lifelong students already working in the automotive technician field.

Table 2 lists the contents of the two HEV courses. The development of these courses is based on an existing HEV course (MCT6150 - Hybrid Vehicle Technology) currently offered at WSU, input from industrial partners, and manuals and training materials provided by HEV manufacturers. The course development activities include the initial development of the course materials, delivery of the course, and modification of the course contents and materials based on student feedback. The finalized course materials will be posted on WSU and MCC web sites for dissemination.

## Two-Day Short Course Development

In addition to the two fundamental HEV courses, a two-day short course is developed for automotive engineers who wish to gain an in-depth understanding of hybrid powertrain configurations and their energy management schemes. The course consists of three modules as listed in Table 3.

| Hybrid Vehicle Fundamentals | Hybrid Powertrain and Control |
|---|---|
| HEV facts:<br>Brief background<br>Operational advantages<br>Operational disadvantages | Energy and power considerations:<br>Energy capacity and energy density<br>Power and power density<br>Overview of electro-mechanical energy converters<br>Recharge power levels<br>Limits on regenerative braking systems |
| Legislative and regulatory considerations:<br>Relevant regulatory agencies<br>Existing regulations | Characteristics of internal combustion engines:<br>Torque and power curves<br>Comparison to electric motors<br>Efficiency maps |
| Introduction to HEV strategies:<br>Vehicle performance requirements<br>Vehicle power usage patterns<br>Series and parallel hybrids<br>Other Hybrid classifications | Characteristics of electric motors:<br>Available types of electric motors<br>Torque curves<br>Power ratings<br>Controller strategies |
| Important additional considerations:<br>Structural integrity<br>Safety (i.e., crash, explosion, shock)<br>Manufacturability (production & prototyping)<br>Availability & cost of various components<br>Occupant amenities | Characteristics of battery and battery packs:<br>Discharge curves<br>Reconciling the inconsistency of available data<br>Present and near-term battery technology |
| Likely directions of future technology:<br>Advanced battery technology<br>Flywheels<br>Ultra-capacitors<br>Turbines and fuel cells | HEV transmission and torque converter:<br>Electrical transmission system<br>Types of transmissions used in HEV<br>HEV control strategy:<br>Vehicle lunched by battery and motor<br>Engine start and stop at city driving cycle<br>Fuel cut-off during vehicle deceleration |

TABLE 2
COURSE CONTENTS FOR THE TWO HEV TECHNOLOGY COURSES

## Seminars and Workshops Development

The MCC has offered a variety of workshops and seminars to various groups with a stake in learning more about HEV technology. These workshops and seminars are tailored to meet the specific needs of each group. More specifically, we created:

1. Workshop for K-12 Technology Teachers: 40 secondary schools and approximately 120 teachers provide a forum for this project to educate technology teachers.
2. Workshop for emergency first responders: First responders to traffic accidents (i.e., police, fire, and ambulatory personnel) need to be educated on the safety

practices with respect to HEVs. Police and fire academies are located on the MCC campus and are instrumental in the design, instruction, and marketing of these workshops.

3. Informational seminars for corporate partners: These seminars are made available in conjunction with the local automobile dealers association.
4. Informational seminars for automotive repair facilities: There are approximately 4,845 regional repair facilities. These seminars intend to introduce the technology and safety of hybrid electric vehicles.
5. Informational seminars for the general public: These seminars focus on safety, which may be offered for credit and non-credit.

| Modules | Contents | Lecture hours |
|---|---|---|
| Hybrid Vehicle Fundamentals – Overview | Concepts and impacts<br>Hybrid power units<br>Hybrid power system configurations | 4 |
| Electric Machines and Power Systems | Electric motor characteristics and types of hybrid power units<br>Electric energy storage systems<br>Battery packs with charging/discharging and regenerating systems<br>Power electrics (inverter and dc-to-dc converters) | 4 |
| Modeling and Analysis of Hybrid Vehicles | Vehicle control systems simulation<br>Vehicle data (mass, tire rolling resistance, road load) and driving cycles (city, highway and US06)<br>Types of hybrid powertrain architectures and drive train simulation<br>Vehicle energy management simulation: fuel economy and vehicle performance predictions | 6 |

TABLE 3
COURSE CONTENTS FOR THE TWO-DAY PROGRAM

## Framework for Automotive Service Excellence Certification

The MCC plans to initiate a pilot program for Automotive Service Excellence (ASE) certification in hybrid vehicle technology. The current automotive technician program is ASE certified in all eight areas in which ASE offers certification. Currently ASE does not offer a certification program in HEV technology – a gap that may be filled with this HEV program for automotive technicians. The program's potential to become the pilot program for ASE certification in hybrid electric vehicles extend the program's impact on the auto industry nationally and shape HEV automotive programs across the country in community colleges seeking ASE certification.

## Student Transfer Credit Evaluation and Advising

Faculty from each institution collaborate, along with their industry partners, to create corresponding courses that will benefit their students collectively, and provide for a smooth track within the existing Associate and Baccalaureate programs in automotive technology and engineering technology, respectively. Particularly, the WSU faculty holds a bi-weekly student advising session at the community college campus for student

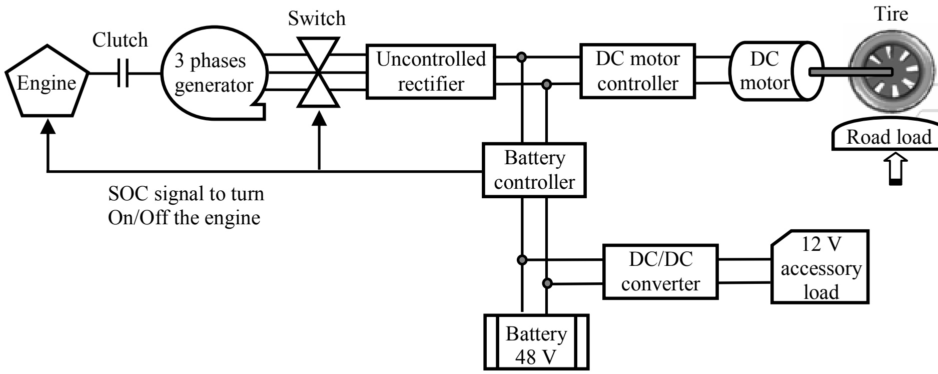



FIGURE 1
SCHEMATIC DIAGRAM OF THE PROPOSED SERIES HYBRID VEHICLE LAB SETUP

transfer credit evaluation. The advising sessions aim to provide community college students the guidelines for pursuing the Bachelor of Science Degree in Engineering Technology (BSET) at WSU, and the plans for maximizing their transfer credits.

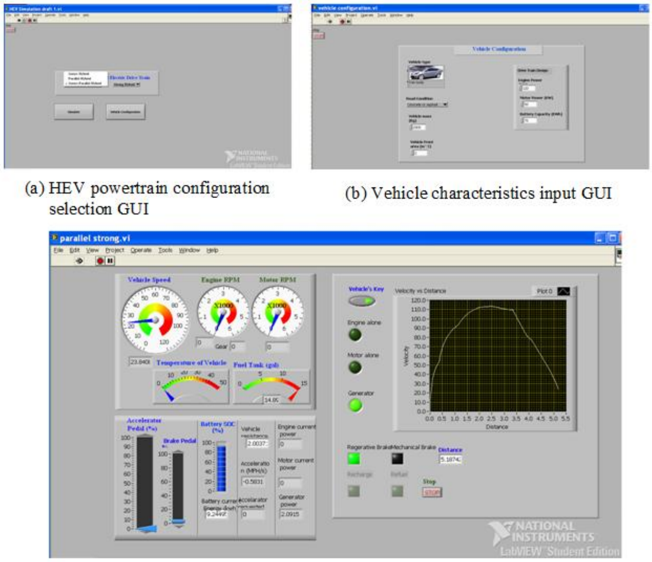
## HEV SPECIALIZED LABORATORY DEVELOPMENT

In order to make the HEV curriculum an integrated part of the existing Automotive Technology program, the equipment specifically required for the HEV laboratory includes:

- Regenerative braking scanners and system bleeder
- Battery power systems and diagnostic tools
- Hybrid simulation devices
- Vehicle control systems diagnostic tools
- Hybrid propulsion mock up

The above laboratory equipment is stand-alone sub-system. It is no doubt that a full function of HEV laboratory will not only enhance the HEV training and education, but also increase student interest in the green movement of transportation. However, the full function HEV laboratory needs tremendous capital investment and manpower, as well as tedious and time-consuming. To overcome this issue, a low-cost, bench-type, full function series hybrid vehicle powertrain laboratory is established on the basis of Formula Hybrid Society of Automotive Engineers (SAE) [27].

Figure 1 shows the schematic diagram of the series hybrid vehicle system that was implemented. It is a state-of-the-art 5 kW series hybrid vehicle demonstration unit. A three-phase AC generator is operated by an engine in the system. A battery controller (or a battery management system) is applied to manage the charging and discharging process of the battery pack. A DC motor controller drives the motor to achieve the desired torque-speed characteristic curve. The motor shaft connects to a tire that contacts with a rotating drum. The load applied to the tire from the drum simulates the road load. The technical specifications and requirements for the components are listed in Table 4.




(a) HEV powertrain configuration selection GUI

(b) Vehicle characteristics input GUI

(c) Simulation result

FIGURE 2
EXAMPLE OF GUIS AND SIMULATION RESULT

## VIRTUAL HEV SIMULATOR

This project also developed an interactive, LabVIEW-based [28] simulation software for various configurations of hybrid powertrains under several driving conditions. The tremendous capital investment, tedious and time-consuming tasks required to establish a full function of HEV laboratory are convincing evidence that the colleges and secondary schools are in need of a low-cost, computer-based virtual HEV simulator. The developed software package is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions. The software integrated with an actuator assembles the simulator which serves as a hands-on experience unit for multidiscipline students enrolled in the HEV technology courses. The virtual HEV simulator will not only enhance the HEV training and education, but also inspire students interest in the green movement of transportation.

The simulation software comprises two categories in terms of the degree of powertrain hybridization: mild and strong HEVs. Each category has several commercially available HEVs. The features of HEVs including engine idle stop-start, engine-off driving for vehicle launch, power boost, battery charging from engine, and energy recapture (regenerative braking) are implemented in the simulator. The control strategy, which determines the energy flow in the HEV, was pre-defined and hard-coded in the software.

| Component | Specifications | Remarks |
|---|---|---|
| Engine | Horizontal, 1800 RPM, 5 kW | A speed reduction gear box is needed to operate the engine output speed at 1800 RPM. |
| Generator | Three phase AC generator, 60 Hz, 4 pole, 1800 RPM, 5 kVA, 120/208 V | A brushless synchronous generator is preferred.<br>Other types of AC generators may also be suitable. |
| Switch/Circuit Breaker | 250 VAC, 30A, three phase | The switch can be controlled to automatically turn ON and OFF |
| Uncontrolled Rectifier | Input: 3 phases 120/208 VAC<br>Output: 270V DC<br>Power: 5 kW | |
| Battery Controller | High DC: 300V<br>Low DC: 48V<br>Bidirectional power flow<br>Battery SOC state indication and output<br>Battery charging and discharging control<br>Rated charging power: 5 kW<br>Rate discharging power 5 kW<br>Short-time power factor: 2.5 | The controller is required to stand a short-time charging power which could be several times higher than its rated charging power. On the other hand, it is also required to supply a surge power for starting. |
| DC motor controller | Input: 270 VDC<br>Output: Variable<br>Power: 4 kW<br>Speed control range: 0-3600 rpm<br>Bi-directional power flow | This drive needs to be capable of bi-directional power flow.<br>The drive may be purchased together with the motor. |
| DC motor | Voltage: 110 V DC<br>Power: 4 kW<br>Rated speed: 1800 rpm<br>Separated excitation | |
| Battery | 48 V, 10 kWh, High Capacity Lead Acid, or Nickel Metal Hydride | It can be achieved using 12 V batteries.<br>High current switches capable of switching 100 A or more may also needed to provide the necessary interconnections. |

TABLE 4
COMPONENT SPECIFICATIONS FOR BENCH-TYPE SERIES HYBRID POWERTRAIN

| Year One | Workshop/Course | Participants | Number of students |
|---|---|---|---|
| 3/28/2006 | workshop | SEMATA (K-12 teachers) | 110 |
| 6/29/2006 to 6/30/2006 | WSU Two-day HEV short course | Community college automotive program instructors and K-12 technology teachers | 23 |
| Spring term 2006 | WSU MCT6150 (HEV Technology course) | WSU undergraduate and graduate students | 22 |

TABLE 5
SUMMARY OF THE FIRST YEAR ACTIVITY

The control strategy is adopted from those algorithms commonly implemented in the current production type HEVs. The computation is based on the vehicle power demand and the energy balance of mechanical and electric energies. The driving condition is input by user through an actuator integrated with the LabVIEW software. This driving condition represents the vehicle speed controlled by the user via vehicle accelerator. Based on the driving condition and pre-defined control rules, the simulator displays the energy flow in the computer screen.

An example of GUIs and simulation result is illustrated in Figure 2. Figure 2(a) shows the GUI for selecting HEV powertrain configurations (series, parallel, or series-parallel) and degree of powertrain hybridization (mild or strong). Figure 2(b) shows the GUI to input vehicle characteristics, such as vehicle mass, engine power, electric machine power, and battery capacity, etc.). Figure 2(c) is an example of simulation result of vehicle speed versus time displayed in the upper-right curve plot.

## RESULTS AND DISCUSSIONS

The implementation of the HEV learning system was a resounding success. It was able to provide instruction on HEV technology workshops, short courses, and regular semester courses to 2183 participants (155 in the first year, 921 in the second year and 1107 in the third year) over the last three years (8/2005 to 7/2008). MCC and WSU had received much nice coverage in the local media on the grant and HEV program. Two web pages highlighting the grant and HEV program were established. The workshops, short courses, and regular semester courses were developed in the first two years.

In the first year (8/2005 to 7/2006), WSU faculty completed and delivered condensed course materials for MCT6150 (Hybrid Vehicle Technology) to assist MCC faculty in developing the course and workshops. MCC faculty developed curriculum for the basic automotive class (AUTO1000) and delivered the materials beginning in the winter 2006 term. Simultaneously, faculty developed the first workshop session for K-12 teachers. This initial "short" session was delivered at a meeting of the Southeast Michigan Automotive Teachers Association (SEMATA) in March 2006. Approximately 110 teachers and administrators attended the session. WSU offered MCT6150 regular course in Spring term 2006 and 16-hour short course during the Summer of 2006. The short course targeted community college automotive program instructors and K-12 technology teachers. WSU also tailored the 16-hour course into an 8-hour introductory HEV course for workforce training and professional development. The course was scheduled once per month, starting April 2006, at the Michigan Technical Educational Center in St. Clair County Community College, Michigan. Table 5 summarizes the activity in the first year.

In the second year (8/2006 to 7/2007), MCC integrated the HEV courses into the Automotive Technology program, this integration will assist in sustaining the HEV courses upon completion of the project. MCC offered three courses, AUTO1000 (HEV modules), AUTO1440 (HEV Fundamentals), and AUTO2440 (HEV Powertrain and Controls), in year two. MCC also participated in the American International Auto Show on 1/17/2007. Faculty participated in display session and provided HEV updates to interested individuals. The activity in the second year was summarized in Table 6.

| Date | Workshop/Course | Participants | Number of students |
|---|---|---|---|
| 8/8/2006 | workshop | Emergency first responder | 21 |
| 10/5/2006 | symposium | Corporate auto facilities | 120 |
| 12/13/2006 | event | General public | 50 |
| 1/17/2007 | workshop Detroit International Auto Show | General public | 200 |
| 3/10/2007 | workshop | Independent repair auto value - Milwaukee | 65 |
| 4/20/2007 | workshop | Independent repair auto value - Lansing | 85 |
| 5/22/2007 | workshop | SEMATA | 22 |
| 6/29/2007 to 6/30/2007 | WSU Two-day HEV short course | Community college automotive program instructors and K-12 technology teachers | 44 |
| Winter term 2007 | WSU MCT6150 (HEV Technology course) | WSU undergraduate and graduate students | 18 |
| Fall term 2006 | MCC AUTO1000 (HEV modules) | MCC undergraduate students | 166 |
| Winter term 2007 | MCC AUTO1000 (HEV modules) | MCC undergraduate students | 100 |
| Fall term 2006 | MCC AUTO1440 (HEV Fundamentals) | MCC undergraduate students | 20 |
| Winter term 2007 | MCC AUTO2440 (HEV Powertrain and Controls) | MCC undergraduate students | 10 |

TABLE 6
SUMMARY OF THE SECOND YEAR ACTIVITY

| Date | Workshop/Course | Participants | Number of students |
|---|---|---|---|
| 11/8/2007 | workshop | SEMATA | 40 |
| 2/15/2008 | workshop | Independent repair auto value - Milwaukee | 65 |
| 3/4/2008 | workshop | Automotive Service Association - Warren | 35 |
| 3/11/2008 | workshop | Automotive Service Association – Grand Rapids | 50 |
| 3/18/2008 | workshop | Automotive Service Association – Kirtland | 30 |
| 3/28/2008 | workshop | Independent repair auto value - Grand Rapids | 45 |
| May and June, 2008 | extended HEV workshop for automotive students | Utica High School | 65 |
| 5/12/2008 | workshop HEV First responder/safety | Paramedic Academy | 30 |
| 7/11/2008 | workshop HEV First responder/safety | Paramedic Academy | 28 |
| Winter term 2008 | WSU MCT6150 (HEV Technology course) | WSU undergraduate and graduate students | 21 |
| Fall 2007, Winter 2008 | MCC AUTO1000 (HEV modules) | MCC undergraduate students | 637 (20 classes) |
| Fall term 2007 | MCC AUTO1440 (HEV Fundamentals) | MCC undergraduate students | 41 |
| Winter term 2008 | MCC AUTO2440 (HEV Powertrain and Controls) | MCC undergraduate students | 20 |

TABLE 7
SUMMARY OF THE THIRD YEAR ACTIVITY

The project continued to meet the activities outlined in the proposal in the third year (8/2007 to 7/2008), as illustrated in Table 7. In addition, WSU and MCC had the opportunity to present additional HEV courses and workshops that were within the scope of the HEV project, but were not in the original planned activities. Additional HEV workshops were developed and conducted for the Macomb Paramedic academy. These workshops were developed and presented based on the positive feedback about the First Responder sessions from fire instructors and local fire departments. A HEV class was developed and presented at Utica High School. This class was offered to provide their students with advanced automotive training in HEV.

## SUMMARY

Given heightened concerns over the environmental and limited fossil fuels, a clear trend toward hybrid electric vehicles is emerging. Currently automobile manufacturers are training their HEV engineers and technicians entirely "in-house," which limits the number of automotive engineers and technicians available for the growing hybrid vehicle market. There is a clear need for a systematic training program on HEV. This paper describes a funded project whose goal is to fill this need by developing an integrated learning system for HEV technology. This project targets engineering/engineering technology students in 4-year universities, automotive technology students in community colleges, automotive engineers and technicians in industries, and K-12 technology teachers.

In order to develop this project, a partnership was formed between faculty of MCC automotive technology program and the engineering technology program at WSU. The partnership also includes industrial partners from major automobile manufacturers and suppliers. The activities for the project include (1) Developing an HEV curriculum and integrating it with the existing Associate of Applied Science program in Automotive Technology; (2) Revising existing courses and developing required HEV specific courses; (3) Creating an HEV specialized laboratory; (4) Developing a two-day short course on HEV technology available for distance learning; (5) Developing and delivering seminars and workshops for various groups of audiences, including K-12 teachers, (6) Creating internship and co-op opportunities, plant visits, and an expert lecturer series; (7) Initiating a pilot program for Automotive Service Excellence certification in hybrid vehicles; and (8) Providing transfer student advising by university faculty.

This project also designed and implemented a low-cost, bench-type, full function series hybrid vehicle powertrain laboratory on the basis of Formula Hybrid SAE. Additionally, interactive LabVIEW-based simulation software was developed for various configurations of hybrid powertrains under several driving conditions. The developed software is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions. The developed bench-type series hybrid powertrain laboratory and LabView-based virtual HEV simulator serves as hands-on experience units for multidiscipline students enrolled in the HEV technology courses. The full function hybrid powertrain laboratory and virtual HEV simulator not only enhance the HEV training and education, but also inspires students' interest in the green transportation.

It is our intent in this project to develop collective effort, among educators, industry, and government agency, to make positive, continual, and lasting contribution for education on the emerging technology for green transportation. The implementation of the HEV learning system was a resounding success. It was able to provide instruction on HEV technology workshops, short courses, and regular semester courses to 2183 participants over the last three years. The work is still ongoing and initial student reaction has been quite enthusiastic.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Vehicle Technologies Program, U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Oil Imports, Today and Tomorrow," http://www1.eere.energy.gov/vehiclesandfuels/facts/2007_fcvt_fotw456.html/. February 12, 2007.
2. A. F. Burke, "Hybrid/Electric Vehicle Design Options and Evaluations," *Society of Automotive Engineers (SAE), Paper* 920447, 1992.
3. J. J. Ronning, and G. L. Grant, "Global Hybrid Electric Vehicle Markets and Missions," *SAE Paper* 1999-01-2946, 1999.
4. J. Walter, H. Husted, and K. Rajashekara, "Comparative Study of Hybrid Powertrain Strategies," *SAE Paper* 2001-01-2501, 2001.
5. K. Hirose, S. Abe, and G. Killmann, "Overview of Current and Future Hybrid Technology," *SAE Paper* 2002-33-0016, 2002.
6. P. R. Henry, B. Lequesne, S. Chen, J. J. Ronning, and Y. Xue, "Belt-Driven Starter-Generator for Future 42-Volt Systems," *SAE Paper* 2001-01-0728, 2001.
7. H. Kusumi, K. Yagi, Y. Ny, S. Abo, H. Sato, S. Furuta, and M. Morikawa, "42V Power Control System for Mild Hybrid Vehicle (MHV)," *SAE Paper* 2002-01-0519, 2002.
8. G. Tamai, M. Jeffers, C. Lo, C. Thurston, S. Tarnowsky, and S. Poulos, "Development of the Hybrid System for the Saturn VUE Hybrid," *SAE Paper* 2006-01-1502, 2006.
9. D. Evans, M. Polom, S. Poulos, K. VanMaanen, et al., "Powertrain Architecture and Controls Integration for GM's Hybrid Full-Size Pickup Truck," *SAE Paper* 2003-01-0085, 2003.
10. D. Evans, and K. VanMaanen, "Electric Machine Powertrain Integration for GM's Hybrid Full-Size Pickup Truck," *SAE Paper* 2003-01-0084, 2003.
11. A. Kabasawa, and K. Takahashi, "Development of the IMA Motor for the V6 Hybrid Midsize Sedan," *SAE Paper* 2005-01-0276, 2005.
12. K. Hanada, M. Kaizuka, S. Ishikawa, T. Imai, H. Matsuoka, and H. Adachi, "Development of Hybrid System for the V6 Midsize Sedan," *SAE Paper* 2005-01-0274, 2005.
13. J. Meisei, "An Analytic Foundation for the Toyota Prius THS-II Powertrain with a Comparison to a Strong Parallel Hybrid-Electric Powertrain," *SAE Paper* 2006-01-0666, 2006.
14. Y. G. Liao, T. R. Weber, and D. P. Pfaff, "Modelling and Analysis of Powertrain Hybridization on All-Wheel-Drive Sport Utility Vehicles," IMechE, *Journal of Automobile Engineering*, Vol. 218/D, 2004, pp. 1125-1134.
15. "Hybrid Vehicle Sales on Pace to Reach Record Sales in 2007," *JD Power and Associates*, www.jdpower.com, August 2, 2007.
16. K. Denton, J. Goldman, B. Hays, and C. Hyatt, "2000 University of Maryland FutureTruck Design Description," *SAE Paper* 2001-01-0681, 2001.
17. J. Conley, B. Caly, R. Waters, et al., "The Development of a Fourth Generation Hybrid Electric Vehicle at West Virginia University," *SAE Paper* 2001-01-0682, 2001.

18. J. Adcock, B. Allen, et al., “Design and Construction of the University of Tennessee, Knoxville FutureTruck 2000/2001 Parallel Hybrid Vehicle,” *SAE Paper* 2002-01-1213, 2002.

19. M. Parten, T. Maxwell, and J. Jones, J., “Advanced Vehicle Research in a Multidisciplinary Project Laboratory,” *Proceedings of American Society for Engineering Education (ASEE)*, Annual Conference and exposition Section *3626*, 1999.

20. J. Talbert, F. Wicks, and R. Wilk, “Evaluating the Benefits of Hybrid Electric Vehicles Concepts,” *Proceedings of ASEE*, Section 2633, 2001.

21. M. Rizkalla, C. Yokomoto, R. Pfile, A. Sinha, M. El-Sharkaway, S. Lyshevski, and A. Al-Antably, “Application of Computer-Based Power Electronics to Electric Vehicle Technology, An Interdisciplinary Senior Course,” *Proceedings of ASEE*, Section 3432, 2000.

22. T. Chau, and C. Chan, “Electric Vehicle Technology – A Timely Course for Electric Engineering Students,” *Int. Journal of Electrical Engineering Education*, Vol. 35, 1998, pp. 212-220.

23. Y. Guezennec, G. Rizzoni, G. Washington, and S. Yurkovich, “The OSU-GATE Program: Development of a Graduate Program in Hybrid Vehicle Drivetrains and Control Systems at the Ohio State University,” *Proceedings of ASEE*, Section 2255, 2001.

24. “Mechanics Fear Hybrid Vehicles,” Associated Press article published in Macomb Daily, June 23, 2004.

25. N. S. Edward, “A Progressive Approach to Professional Development,” Chap. 14, W. Aung, et al. (eds.), *Innovations 2008: World Innovations in Engineering Education and Research*, Int. Network for Eng. Ed. and Res. (iNEER), Arlington, VA, 2008, pp. 145-156.

26. S. Petrovic, and L. Munukutla, L., “An Integrated Alternative Energy Technologies Program,” Chap. 22, W. Aung, et al. (eds.), *Innovations 2008: World Innovations in Engineering Education and Research*, iNEER, Arlington, VA, 2008, pp. 243-250.

27. “Formula Hybrid,” *SAE International*, http://www.formula-hybrid.org/. Accessed March 17, 2009.

28. National Instruments, LabVIEW, http://www.ni.com/products/. Accessed March 17, 2009.

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