Transportation Electrification Education for K-12 Students

Ian A. Hiskens Huei Peng Hosam K. Fathy

***Abstract*—The paper describes a range of educational activities that are being developed to provide opportunities for K-12 students to learn about vehicle electrification. Whilst the focus is primarily on technology, students are also encouraged to consider environmental and societal impacts. Activities include development of school-based learning materials, summer camps, and a toolkit that brings together simulation and physical models, allowing children to play with electric vehicles. This K-12 outreach is part of a larger project, funded by the Department of Energy, to develop a comprehensive educational program in vehicle electrification.**

***Index Terms*—Electric vehicles; K-12 education; simulation; hardware-in-the-loop.**

I. Introduction

A successful transformation to electrified transportation will require changes beyond those occurring within the automobile manufacturers alone. Coordinated changes among government agencies and policy makers, utility companies, providers of green energy devices and systems, maintenance and repair technicians, higher education institutes, and consumers are also crucial. Education and training can play a key role in promoting these changes, especially if synergistic efforts from multiple institutions are established and facilitated.

The K-12 educational activities discussed in this paper are part of a much larger educational project that has been funded by the Department of Energy. The guiding principles of this project are:

(i) The education programs must be driven by research excellence and industrial relevance.
(ii) A win-win relationship among academic and industrial partners can be formed through planned teaming, sharing, leveraging and disseminating.
(iii) We need to develop excellent academic courses first to have a solid education foundation, and then distill them into knowledge nuggets that are suitable for broader dissemination and sharing, as well as to bundle them into in-depth specialty and concentration curriculum.
(iv) It is important to engage in broader outreach activities including K-12 and public education, to ensure a long-term and sustainable impact on society.

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A major challenge in devising a meaningful education proposal for transportation electrification arises from its interdisciplinary nature. Electric vehicles involve energy storage systems and fuel cells (chemistry and materials), electric drives and power electronics (electrical engineering and some mechanical engineering), transmissions (mechanical engineering), controls (electrical and mechanical engineering), and in the case of plug-in electric vehicles (PEVs), grid and communications infrastructures (electrical engineering). In this context the traditional approach of (mostly) relying on a single instructor from a single department for course development and delivery is clearly insufficient. To have real impact, the educational effort must embrace team contributions and cross-departmental collaboration. In team teaching of this form, each faculty member teaches a subset of the topics in their area of expertise. Students benefit from the broader knowledge and experience of the instructors.

In addition to educating the next generation of engineers/technicians in the area of electric drive vehicles, it is clear that the ultimate success of these vehicles will depend upon consumer demand. To broaden the reach and amplify the impact of our project, we are conducting a wide array of educational activities aimed at informing K-12 students and the general public about the advantages and fundamentals of electric vehicles.

The focus of this paper is on the K-12 educational activities. Section II presents an overview of classroom activities that are under development for high school students. A summer camp program for high school students is discussed in Section III, and Section IV describes an education kit that is intended for K-12 students. Conclusions are presented in Section V.

II. High school activities

The first generation of PEV users can be found in high schools. That group will also yield the technicians, engineers and scientists who will ultimately drive the on-going development of PEV capabilities. Providing high school students with opportunities to experience and understand PEVs is therefore an important component in gaining widespread community acceptance of PEVs. Furthermore, introducing high school students to the “cool” technology of PEVs will have a cascade effect. As they share their interest and excitement with family and friends, the students will help educate the wider community. By breaking down the barriers that arise from uncertainty and misconceptions, this education process will help accelerate the adoption of PEVs into the mainstream automotive market. Another benefit is that PEVs may provide a hook for helping students appreciate the importance of science and mathematics.

High school activities have initially been developed in conjunction with Huron High School, which is located less than two kilometers from the Ann Arbor campus of the University of Michigan. This proximity has made interactions very convenient. Also, connections already existed between university faculty and the science and math teaching staff at the high school. Course development is an on-going process; once course material has stabilized, it will be made available to other high schools that have an interest in introducing similar programs.

The project is addressing four different forms of educational activities. In establishing this program, the aim has been to achieve wide exposure of basic PEV concepts, while also allowing deeper investigations for students who have more advanced science and mathematics skills. The following descriptions provide an overview of each of the four activities.

A. Junior/senior physics

The physics curriculum is structured to enable students to take the Advanced Placement (AP) exam. It is therefore difficult to make substantial alterations to the curriculum. The most effective way of introducing PEV material is via a sequence of eight lessons, with one lesson being taught every four weeks throughout the school year. Each of the eight lessons focuses on a particular topic, and will ultimately be preceded by preparatory reading material, and accompanied by a mini research project. The current version of the lesson plan has structured material into the following modules:

1) Introduction to conventional vehicles: powertrain, internal combustion engines, hybrid vehicles.
2) Motors and generators: DC motors, synchronous motors, induction motors, generators.
3) The electricity grid: basic grid operation, power production, electricity distribution, transformers, home energy usage, PEV charging.
4) Batteries: basic electrochemistry, different battery types and uses, energy and power density, life degradation, climate effects, battery safety, vehicle-to-grid.
5) Life cycle assessment, sustainability, and environmental impact: life cycle assessment of solar panels, comparison of energy sources, grid efficiency, comparison of energy usage for PEV and conventional vehicles, alternative fuels.
6) Vehicle control systems: open and closed loop control, feedback, drive cycles, optimizing energy use.
7) Power electronics: history of AC versus DC, four basic AC/DC conversion processes, devices, use in PEVs, electro-magnetic interference.
8) Other topics: business models, economics of PEV ownership, recharging logistics, production and maintenance of PEVs, safety.

The initial versions of these modules have been developed by a Senior student from Huron High School, in conjunction with his high school physics teacher, and with content input from university faculty.

B. Freshman/sophomore courses

The math/science background of typical freshman and sophomore students does not support anything more than a superficial treatment of electric vehicle concepts. Even so, the standard curriculum provides opportunities for electric vehicles to be used as examples and illustrations. The project has been evaluating existing curricula in order to identify opportunities for adding targeted examples. Although this process won't result in explicit coverage of vehicle electrification, it will nevertheless enable students to gain familiarity with relevant concepts and characteristics.

C. "Know your auto" classes

Numerous high school students prefer hands-on learning experiences to the regular classroom environment. The project is designing modules that provide an interactive presentation of electric vehicle technology. The design process is borrowing ideas and experiences from the development of related university laboratory courses. The emphasis is on more practical aspects of hardware interactions.

III. Summer camp for high school students

In addition to educating the next generation of the workforce in the area of electrified vehicles, it is clear that the success of these vehicles also depends on consumer demand and acceptance. To broaden our reach and amplify our impact, we designed and offered a summer camp to a small group of K-12 students with the goal of informing them about the challenges and fundamentals of electrified vehicles. Another goal is to attract these students - many of them 11th graders, and in the process of applying to colleges - to the field of Science, Technology, Engineering and Mathematics.

In the summer of 2010, we offered a 3-day summer camp at the Ann Arbor campus of the University of Michigan. The camp involves seven faculty members from the Ann Arbor and Dearborn campuses. There were three main parts of the camp:

1) The energy and environmental needs and overview of the advanced technologies necessary for the realization of electrified vehicles;
2) Field trip to selected local companies to give the campers first-hand experience of the current state of development related to electrified vehicles;
3) A lab session to put together an electric toy vehicle which culminated in a final competition.

The lectures were designed to cover a broad array of topics related to electrified vehicles. We first started with a review of the current status of energy supply and demand in the transportation sector, with a focus on the status of the United States and China. After the introduction of the big picture, the challenges and pros/cons of various possible solutions were discussed. Current market and technologies useful for today's and future hybrid vehicles were then introduced, including batteries, motors, power electronics, fuel cells, and advanced electric grid. Students were organized for in-class discussions and also in-lab training. As part of the battery lecture, students were divided into groups and each group had the chance to

Fig. 1. A camper putting together a button Li-Ion battery.

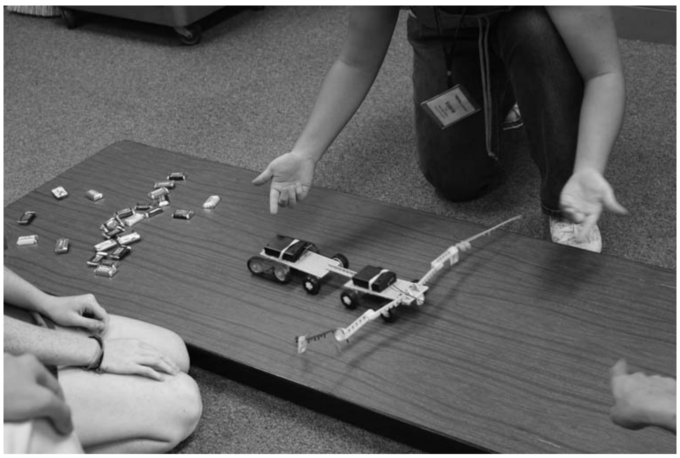

Fig. 2. An electric vehicle going through the obstacle course.

assemble a button battery cell, and test its performance. This activity is shown in Figure 1.

At the end of the first day, students were organized into groups of two. A basic vehicle performance and motor lecture was given, and a toy electric car kit was given to each team. The goal of the competition was announced: that they needed to learn how to put together the electric car, selecting the powertrain (transmission gear position, wheel/track) and then compete over three challenging courses. The first course was an eight-foot long flat track and the purpose was to compete for speed. The second course involved a 30-degree climb and again they needed to compete for speed. The final course was the obstacle course shown in Figure 2. (The course was littered with dozens of mini chocolate bars.) The teams then competed by going over these obstacles without falling off the challenge course. Each team was also given only two sets of fresh batteries which they needed to use judicially and strategically throughout the testing and competition phases.

The whole second day was devoted to a field trip. The field trip was attended not only by students, but also by graduate students and faculty members involved in the summer camp. The first stop was at the Michigan Solar Car team garage located in Ypsilanti, MI. We then arranged visits to three local companies: General Motors Milford Proving Ground, Ford Research campus and ITC Transco. At both GM and Ford, we had the chance to tour their research facilities and ride in some of their prototype electrified vehicles. At ITC Transco, the students were introduced to the operation of the electric grid and the integration of electrified vehicles and renewable power sources to the grid.

On the third day we had several more lectures, on hydrogen and wind power. In the middle of the day the students were given a tour of the College of Engineering research facilities, including laboratories engaged in batteries, hybrid powertrains and power electronics research and education. In addition, they undertook the standard tour given to all prospective students. The last session of the camp was an electric toy vehicle competition. One graduating high school student and two graduate students were recruited to run the competition. The camp closed after the award ceremony, in which the top three teams received prizes and all students shared the mini chocolate bars they conquered.

It is difficult to assess how much was achieved in promoting awareness and interest in electrified vehicles, but it seems the participants truly enjoyed the three-day camp. It might also be worthwhile mentioning that more than half of the participants were girls which was a pleasant surprise to us. We plan on offering this summer camp at least twice more, at which time we will evaluate and plan for the next step.

IV. An education kit for electric automobiles

A key goal in our educational outreach activities is to create a toolkit that allows children to explore the fundamentals of transportation electrification while "playing". The kit, currently under development, will introduce children to electric vehicle design using two approaches often used in engineering design,

1) Virtual simulation, and
2) Hardware-in-the-loop (HIL) simulation.

The kit is also providing education, training, and employment opportunities to graduate and undergraduate students, who have been recruited to assist in its development. In the process, they are learning about transportation electrification.

The development of this toy kit is largely inspired by the powerful vision of school children as "self-taught epistemologists". This vision originally appears in Jean Piaget's work on pedagogy, and is adopted and described by Piaget's student, Seymor Papert, in his seminal book *Mindstorms: Children, Computers, and Powerful Ideas* [1]. Papert's book inspired the creation of the LEGO Mindstorms NXT® robotics education toolkit, and our goal is to build a kit grounded in the same epistemological principles, but designed for introducing K-12 children to vehicle electrification.

Figure 3 presents a "pyramid diagram" of the proposed kit. Users will interact with this kit through both an educational "videogame" and a hands-on electric vehicle simulator. The core of the "videogame" consists of a library of generic hybrid powertrain component models from the open literature. Assembling these component models together makes it possible to simulate different electrified vehicles. This, in turn, makes it possible to construct a simulation-based "videogame" that

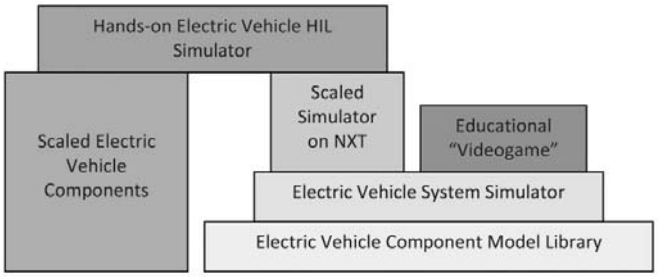

Fig. 3. Pyramid diagram of K-12 education toolkit.

Fig. 4. Screen snapshot of student-created convoy-following videogame.

Fig. 5. Scaled radio-controlled vehicle.

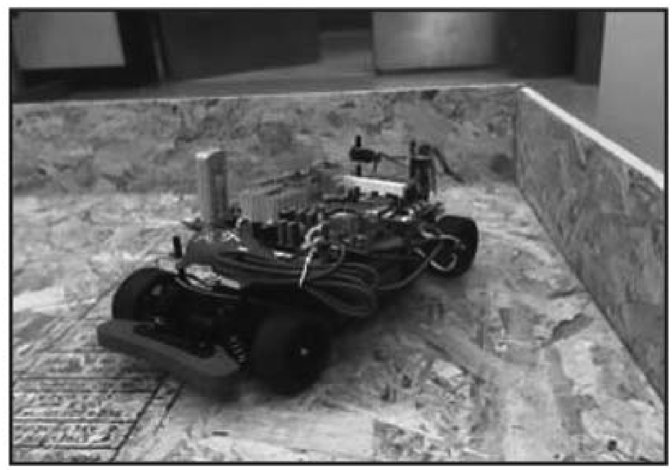

Fig. 6. Experimental vehicle employing hardware-in-the-loop simulation.

allows users to explore the impact of different electrified vehicle design decisions on factors such as performance, fuel economy, etc. The videogame is intended to target young adults at the age when they are first exposed to the complex question of choosing which vehicles to drive. To maximize the videogame's dissemination to this target audience, the game is being designed for distribution through social networking websites/media. Figure 4 shows a screenshot of a similar, more research-focused "videogame" created as part of earlier research on the impact of driver-to-driver variability on vehicle emissions by one of the authors and his collaborators.

In addition to the above videogame, the educational kit is intended to provide K-12 students with hands-on hybrid vehicle construction experience. The target audience for this "toy" component of the kit is 8-11 year-old school children, and our intent is to engage this audience through school summer camps. The "toy" kit will make use of existing commercial radio-controlled toy cars with real, scaled-down internal combustion engines, such as the toy car in Figure 5. These toy cars are being disassembled and retrofitted with electric motors to create a kit that can be assembled by its users into different hybrid vehicle configurations (e.g., series, parallel, through-the-road parallel, etc.). Components of a hybrid powertrain that may be difficult to replicate in hardware will be simulated on an onboard real-time control board such as the NXT brick. Thus, the "toy" component of the educational kit will employ hardware-in-the-loop simulation, in a manner very similar to earlier research by the authors' collaborators, Verma *et al.* (Figure 6) [2].

V. Conclusions

The ultimate success of electric vehicles rests largely with a user base that is currently still in our schools. That group will also yield the technicians, engineers and scientists who will drive the on-going development of electric vehicle capabilities. Providing K-12 students with opportunities to experience and understand vehicle electrification is therefore an important component in gaining widespread community acceptance of this new and transformative technology.

Educational activities should be structured to reach the widest possible audience among K-12 students. Earlier years tend to be motivated by hands-on "play" type experiences. Accordingly, we are developing an educational toolkit for that group that uses virtual simulation and hardware-in-the-loop simulation to create a vehicle-centric educational "videogame". A number of different educational activities are required to reach the broad spectrum of capabilities found in high schools. These developments include an after-school physics curriculum, "know your auto" classes, sets of examples that can be used throughout freshman/sophomore classes, and a summer camp that provides students with a unique blend of university and industry experiences.

VI. Acknowledgments

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References

[1] S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas*. New York, NY: Basic Books, 1993.

[2] R. Verma, D. Del Vecchio, and H. Fathy, "Development of a scaled vehicle with longitudinal dynamics of a HMMWV for an ITS testbed," *IEEE/ASME Transactions on Mechatronics*, vol. 13, no. 1, pp. 46–57, February 2008.

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He is a leading researcher at the University of Michigan Automotive Research Center, and was involved in the design of several military and civilian concept vehicles, including FTTS, FMTV, and Super-HUMMWV. His team designed the power management algorithm for a prototype hybrid electric vehicle designed by Eaton, which later becomes the basis for their commercial hybrid buses and trucks. Thousands of units have been sold worldwide. He has more than 190 technical publications, including 80 in referred journals and transactions.

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