Global Perspectives on Electric Vehicle Education: Part I

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Abstract

In this two-paper set, academics from universities in the Americas, China and Europe discuss educational and pedagogical developments at university level on electric vehicles (EV). EVs, whether battery (BEV), hybrid (HEV) or fuel cell (FCEV), are seen as being a crucial and essential component of sustainable living, and entire industries around the world are evolving to foster the development of electromobility. Thus, university curricula must also adapt. The authors, university by university, investigate the motivations, challenges and adaptations for EV education and the related pedagogy. Aspects of the related curricula are discussed with helpful insights on content and adoption. Challenges and future adaptations are often discussed. Academics from the following universities contribute to the papers, which are presented in two parts in order to cover the topic. Part I: University College Cork (UCC) and US Hybrid (USH), Indiana Institute of Technology (IT), Beijing Jiaotong University (BJTU), and Southern Illinois University Carbondale (SIUC); Part II: Jilin University (JLU), Oregon State University (OSU), Leibniz University Hannover (LUH), and Universidade Federal de Sao Carlos (UFCar).

See Part II for the conclusion to this two-paper set [1].

1 Introduction

The automotive industry is currently undergoing a significant transformation as it embraces electric vehicles (EVs). Societal interest in EVs, and related EV sales, have both grown significantly over the past decade. The interest is spurred by a number of significant factors, such as the reduction of carbon emissions to mitigate climate change, the reduction of toxic tailpipe emissions in urban environments, the increased use of renewable energy with a correlated reduction in the use of fossil fuels for energy security, and the development of green industries.

This technological evolution has significant implications for educationalists globally. Academics at universities are challenged with evolving or transforming university curricula in order to provide appropriate teaching, with the impacts of electromobility being felt across a wide range of disciplines.

The objective of this pair of papers at the *Engineering Education for Sustainable Development* 2020 conference is to provide insights for practicing teachers into educational and pedagogical developments around the world into the teaching of electromobility. While EVs are the main interest of the collaborating academics, the topics of electric aircraft and rail are also discussed as both these transportation fields also heavily embrace electrification.

PART I: J.G. Hayes (UCC) and **G.A. Goodarzi** (CEO/President of USH) have developed a widely-adopted university textbook and related curriculum on EVs. The structure of a teaching stream is presented, beginning with the environmental motivations for EVs and continuing into the core foundational areas of battery, hybrid and fuel cell EV power trains, electromagnetism, traction machines, and power electronics. **J.P. Renie** (IT) has adopted the Hayes-Goodarzi textbook and modified the existing coursework in Indiana Tech's energy engineering program dealing with batteries, fuel cells and energy storage to incorporate current electric drivetrain analyses. See Part II for the conclusions.

X. Yuan (JLU) explains that the EV has been broadly integrated into the teaching across all areas of automotive technologies at JLU. He discusses the studies on the evaluation of the energy, environmental, and economic impacts of electric vehicles, and the corresponding attempts in classes to help conventional automotive engineering students better understand electric vehicles from a macro perspective. **J. Suda** (SIUC) explains that EV studies greatly impact other broad areas of the automobile, such as braking systems and temperature-control systems. She discusses the necessary evolution of the automotive technology curricula at the secondary and post-secondary educational levels to accommodate the automotive industry's critical need for a workforce knowledgeable in EV technology during this pivotal time in automotive history.

PART II: Y. Cao (OSU), who works at the heart of the U.S. aerospace industry, has introduced special topics on the more-electric aircraft (MEA) and the unmanned aerial vehicle (UAV) as an extension of the EV curriculum. **X. Yang** (BJTU) discusses the role and development of rail transit for sustainable urban transport based on industrial and academic experiences. **O. Ogashawara** (UFCar) discusses the development of a course using Active Learning Methodologies to teach BEVs and HEVs. The discipline goals are the design, modeling and simulation of a vehicle for the Formula SAE Electric Competition. The course uses Team-Based Learning, Flipped Classroom, Project-Based Learning and Fishbowl methods. **Dr. Friebe** (LUH) discusses developments at Leibniz University Hannover.

2 Development of an EV textbook and curriculum at University College Cork (J.G. Hayes & G.A. Goodarzi)

2.1 Background

Prior to joining UCC as a power electronics academic in 2000, J.G. Hayes spent the decade of the 1990s working in Los Angeles developing the power electronics and drives for the General Motors EV1, the first production EV of the modern era. Whilst at UCC, he has continued to be involved with automotive research and regularly includes EVs as part of the curriculum. In 2014, Hayes and former General Motors EV1 colleague Abas Goodarzi, now CEO and President of US Hybrid, began writing a university-level textbook on EVs. At the time, it was becoming clear that battery technology had improved significantly and that the governmental and public attitudes to green technologies has shifted enormously from the 1990s. It was also clear that educational resources, such as teaching textbooks, were essential to the coming electrification of society.

2.2 Textbook and Curriculum

The resulting text is primarily an engineering textbook that covers the automotive powertrain, energy storage and energy conversion, power electronics and electrical machines [2]. A significant additional focus is placed on the engineering design, the energy for transportation, and the related environmental impacts. The book contains 16 chapters covering vehicle design considerations, energy sources, electrical machines, power electronics and the basics, as shown in Table I. The material is taught across four years at UCC. An introductory submodule on energy introduces the student to electromobility, sustainability, and the environmental impacts of transportation, such that the freshman student can quantify the related energy densities, carbon emissions, and ranges for different vehicles. The basics of electromagnetism, ferromagnetism, and electromechanical energy conversion (Chapter 16), and dc machines (Chapter 7) are taught to 2^{nd} year (sophomore) engineering students, who have completed introductory electrical circuits and physics. Two related modules are taught to 3^{rd} years, and these build on the students' knowledge of ac circuits and control theory. The first module is taught as a general science module covering vehicular systems (Chapter 2), batteries (Chapter 3), the internal combustion engine and hybridization (Chapter 5), control (Chapter 15), and the permanent-magnet ac machine (Chapter 9). A software project is assigned to model vehicle acceleration using Matlab and Simulink. The second module is more electrical in nature, utilizes hardware laboratories and introduces power electronics, with the non-isolated dc-dc operating in continuous-mode operation (Chapter 11) and the isolated forward (Chapter 12), and ac machines with the induction machine (Chapter 8). The interior-permanent-magnet machine (Chapter 10), power semiconductors (Chapter 11), isolated power converters (Chapter 12), traction inverters (Chapter 13), and power-factor-corrected battery chargers (Chapter 14) can all be covered in final year or at introductory post-graduate level.

Table I: Book content and related teaching at UCC

Chapter	Topic		1st	2nd	3rd		4^{th}/PG
1	Vehicle & Energy Sources	Electromobility and the Environment	Y				
2		Vehicle Dynamics	Y		Y		
3		Batteries	Y		Y		
4		Fuel Cells					Y
5		Conventional & Hybrid Powertrains	Y		Y	Y	
6	Electrical Machines	Introduction to Traction Machines			Y		
7		The Brushed Dc Machine		Y			
8		Induction Machines				Y	
9		Surface-permanent-magnet Ac Machines			Y		
10		Interior-permanent-magnet Ac Machines					Y
11	Power Electronics	Dc-dc Converters				Y	Y
12		Isolated Dc-dc Converters				Y	Y
13		Traction Drives and Three-phase Inverters					Y
14		Battery Charging					Y
15		Control of the Electric Drive			Y		
16	Basics	Electromagnetism, Ferromagnetism, and Electromechanical Energy Conversion		Y			

2.3 Conclusions and Key Learnings:

- Environmental impacts and the sustainability of technology and society can easily be integrated and investigated using the topic of EVs.

- EVs made the related technical topics of energy storage, power electronics, and machines more engaging for both the instructor and the students.
- Multiple modules are required in order to cover the topic.
- A mix of vehicles, energy storage, power electronics, control, and machines throughout each module helps to maintain a holistic and integrated module and maintain interest.
- Software, hardware and research assignments are easily be integrated into the stream.
- The topic is very dynamic and continuous updating of material enhances the teaching.

3 Utilization of EV textbook within curriculum at Indiana Tech (J.P. Renie)

3.1 Background

For the past decade, the J.P. Renie has been instrumental in teaching courses in a new Energy Engineering (ENE) degree program. This program was initially non-ABET accredited, technical in nature, and complementing other ABET accredited traditional programs in Mechanical, Electrical, and Biomedical Engineering offered at Indiana Tech. Multiple courses, covering such energy related topics of wind and solar, ethanol and biofuels, sustainability, thermodynamics, fluids, heat transfer, and HVAC, were developed and taught to a small group of students interested in this newest subset of engineering education. In addition to these topics, a course involving batteries and fuel cells was offered by industry-based adjunct staff. With the publishing of [2], a decision was made to adopt this textbook and to include electric drivetrain dynamics, in addition to an up-to-date study of batteries and fuel cells to best train the students entering this expanding field of technology.

3.2 Course Material

The course began by focusing on the background information for Electromobility and the Environment covered in Chapter 1 [2]. Particular interest was focused on the EPA drive cycle descriptions and the definitions of various parameters dealing with fuel consumption, range and mile per gallon equivalent (mpge). This section concluded with an overview of conventional, battery, hybrid, and fuel cell electric systems, (Section 1.7). This familiarized the student with the characteristics of the various drivetrain architectures as well as introducing the concept of efficiencies throughout the drivetrain leading to an overall well-to-wheel efficiency with a highlight on CO_2 emissions.

With the general physics prerequisite background of the students, the focus is next on vehicle dynamics (Chapter 2). After describing how the vehicle characteristics, such as mass and road load data, for various vehicles can be obtained from the available EPA files, the students were tasked with determining the acceleration profile for vehicles based on the MATLAB and Excel approaches described in the text. The students were able to utilize these computational skills for their final project/presentation for the class.

Since earlier offerings of this course focused primarily on batteries, fuels cells and other energy storage techniques, the next part of the class focused on Chapter 3 (batteries) and Chapter 4 (fuel cells). The work focused on the battery charge/discharge characteristics related to the battery types associated with the electric drivetrain. During the discussion of these chapters, coordination with the chemistry department permitted a basic electrochemistry experiment, wherein several galvanic cells were constructed and voltages measured and compared to standard oxidation/reduction tables. A Hampden hydrogen fuel cell trainer and a corresponding hydrogen fuel cell characteristic experiment were used to highlight the material presented in Chapter 4. In both chapters, the focus on the case study examples of economy of BEV and fuel cell electric vehicles (FCEV) was instructive.

The second half of the class began with a strong focus on the material in Chapter 5, Conventional and Hybrid Powertrains. The class had only limited thermodynamic cycle analyses background and so time was spent discussing the background surrounding the torque/efficiency versus engine speed characteristics as well as brake specific fuel consumption maps for various engine types. This was ultimately tied into the analysis of hybrid-electric (HEV) systems, including series and series-parallel operation. The section on the continuously-variable transmission (CVT) converged with the background of the students enrolled in the course, which precluded any gear dynamic analyses that a traditional mechanical engineering student would possess.

To complete the course, focus was given to Chapter 6, Introduction to Traction Machines, and Chapter 7, Brushed DC Machines. Again, due to the technical background of the students, different types of electric motors in addition to machine specifications such as rated conditions as well as the characteristic curves of a traction machine were introduced. This was then followed by the analysis of the DC machine in Chapter 7, again driven by the students' minimal understanding of AC electric fundamentals. The concepts of permanent-magnet (PM) and field-weakening (WF) motor characteristics, including saturation and maximum speed operation, was highlighted. The case study of the Mars Rover Traction machine completed the in-class discussion for the class.

During the course of the semester, the students were tasked with completing many of the textbook problems provided in Chapters 1 through 7. Additionally, five in-class, 50-minute quizzes were given. As a final project presentation, the students were tasked with selecting a unique BEV from a recently modified list given in Assignment 2.1. Taking the lead from the assignment in Chapter 2 of Modelling a BEV, the students were expected to research their vehicle and perform acceleration analyses as well as drive cycle analysis based on both the EPA Highway and UC06 Supplemental. Such an analysis permitted a calculation of battery capacity range as well as CO_2 emissions based on the local electricity-fuel breakdown.

4 Electric vehicle studies and education practices at Jilin University (X. Yuan)

4.1 Background

The automotive engineering discipline of Jilin University was established in 1955 with the establishment of First Automotive Works (FAW) Group Co., Ltd. in China, which plays a very important role as a base for training talented persons for the automotive industry in China. With more than 60 years of development, a complete automotive engineering education system has been set up. However, the trends of electrification of vehicles pose significant challenges to the existing automotive engineering education system. Since the education system needs to be gradually improved, most of the courses are still based on conventional vehicles. Instead of introducing a large number of new specialized courses for EVs, a general understanding of EVs is integrated into the existing courses to address the connections and differences between EVs and conventional fossil-fuel vehicles. This is preferred for most of the students to adapt to the current diversified development of the automotive industry.

4.2 Studies on the evaluation of EVs

The comparison of EVs and conventional vehicles is always controversial, but is necessary for the multidisciplinary understanding of the automotive industry. Therefore, studies on the evaluation of EVs have been carried out. Generally, the energy and environmental impact of EVs are of greatest concern. Therefore, an analysis shows the relation between EV driving range, energy consumption, and equivalent CO_2 emission is provided in [3]. In this study, combined with the vehicle longitudinal dynamics, life cycle analysis (LCA) is used to address the relationship between vehicle design, vehicle performance and energy, and environmental impacts. In order to better understand the energy consumption characteristics of EVs, using the real-driving emission (RDE) concept for conventional vehicles, a method to evaluate the real-driving energy consumption of electric vehicles has been proposed in [4], where the energy consumption characteristics of EVs and conventional vehicles are compared, and the reason for the significant increase in the energy consumption of EVs on the highway is pointed out. Additionally, economic and policy factors are also very important for the development of the EV industry at the current stage. Accordingly, the impact of the subsidies and non-economic EV promotion policies are modelled and evaluated in [5]. By using the concept of the life-cycle cost, the results show that such non-economic EV promotion policies have a significant impact on improving the competitiveness of EVs, and are more suitable for long-term implementation compared with subsidies.

4.3 Practices in class

A comprehensive EV education system requires a large number of new specialized courses, including electric machines, power electronics, batteries, etc. Adding these courses greatly increases the burden on students. Therefore, one first step tried at JLU has been to add general concepts of EVs to the existing courses. For example, in the control courses, it can be shown that the concepts of the torque and speed control are the same whether the inner loop is an internal combustion engine (ICE) or an electric motor, and the only difference between the ICE and electric motor is the time constant of the torque response. Another example is that when introducing the modelling of a vehicle, just comparing the differences between the universal characteristics of an ICE and the efficiency map of an electric motor, gives an important understanding of EVs, including the fuel/energy consumption estimation, braking regeneration, energy effective operating area, etc. There is even more room for innovation in introductory courses. One example used by Yuan is for a debate contest to be introduced into the course. Students in the class are arranged in groups, and topics related to EVs are given to the debate. It shows that this practice has achieved good results. Students are more proactive in learning relevant knowledge and thinking about the EV industry when preparing for the debate. Some debate topics are listed in Table I.

4.4 Conclusions and Key Learning:

- Due to the rapid deployment and multidisciplinary nature of the automotive industry, the integration of emerging technologies in automotive engineering education systems is challenging.
- Instead of introducing new specialized courses for EVs, general concepts of EVs can be integrated into existing courses in the current education system.
- Facing the current diversified development of the automotive industry, innovation of education is of great value for the students to quickly receive the explosively growing knowledge and to widely adapt to the industry requirements.

Table I: Debate topics in EV class at JLU

No.	Topics		Hints
1	The cost of EV is high compared with conventional vehicles	P	Battery cost and battery aging
	The cost of EV is not high compared with conventional vehicles	N	Maintenance and energy consumption cost Subsidy and intangible cost from promotion policies
2	The technical factors are the primary major barrier preventing the adoption of EVs	P	Driving range and charging rate
	The non-technical factors are the primary major barrier preventing the adoption of EVs	N	Range anxiety, immature market
3	Conventional vehicles are safer than EVs	P	Safety issues caused by the battery
	EVs are safer than conventional vehicles	N	Statistical records
4	EVs are more energy efficient and environmentally friendly than conventional vehicles	P	Powertrain efficiency Emission in urban area
	EVs are not more energy efficient or environmentally friendly than conventional vehicles as expected	N	Life-cycle analysis (LCA)
5	Slow charging will become the major approach in the future	P	Charging convenience (at home) Battery life, Smart grid, V2G
	Fast charging will become the major approach in the future	N	Charging convenience (charging duration) Ultra-fast charging, Limited driving range

P:Positive side, N:Negative side

5 Curriculum Electrification at Southern Illinois University Carbondale (J. Suda)

5.1 Background

Familiarization with electric vehicles is becoming critical to the automotive industry and its workforce, and it is vitally important that employees are properly educated with advanced technologies to become marketable within such a dynamic industry. Curricula, whether at the secondary or post-secondary education level, must encapsulate such technologies to reflect the current and future needs of what is and what will be the automotive industry as we know it [7],[7].

Since the Fall of 2015, J. Suda has been teaching, developing, and researching powertrain diagnostics training in regards to vehicles across propulsion system types (by means of either the internal combustion engine and/or electric machines) within SIUC’s Automotive Technology Department. The Department holds the only 4-year Automotive Technology program in the state of Illinois, as well as being the only Automotive Technology program that resides at a major research institute in the United States. Ms. Suda is currently “electrifying” the Automotive Technology curriculum at this research institute in order to set a standard at university (post-secondary) education level that will eventually bleed to the secondary education level.

5.2 Curriculum

EV-specific curriculum content should (and does) revolve around the following common componentry in industry today: high-voltage safety systems (such as safety interlock, capacitor discharge, and isolation fault circuits), energy storage (including both auxiliary and high-voltage battery technologies) and charging infrastructure, vehicle propulsion (including electric machines and their control systems), and all associated control/temperature management (heating/cooling) systems for these major powertrain components [2], [6].

However, necessary curriculum electrification should involve more than just covering individual pieces of EV componentry, but integrate it within existing technical curricula in an elegant manner (opposed to covering topics into just a couple individual upper-level courses), since the associated subsystems are highly interconnected. Additionally, a restructuring process must occur with the current technical courses to integrate and accommodate for the EV curriculum, since the current structure is based solely around the internal combustion engine. After a restructuring of the curriculum, typical classes such as brakes, steering & suspension, transmissions/transaxles, heating & cooling systems, etc., will be unrecognizable compared to what they are today. Despite commonality with basic sensors (temperature, pressure, speed/position, etc.), diagnostics pertaining to the vehicle powertrain will need modification with electric vehicles coming into play, since the majority of diagnostics currently taught at the secondary and post-secondary education level cover drivability concerns with gasoline/diesel engines only.

Each area of automotive electrification study, not unlike its internal combustion predecessors, should include the following aspects for optimum comprehension of advanced technology: an overview of safety equipment and practices, a historical/societal background of the technology in general, the related emissions & environmental concerns, a fundamental overview of system/sub-system components, a description of each individual component's functionality with associated control systems, example diagrams showing integrated component interconnection/functionality/design, a description of fault-states and analysis within both the component and system/subsystem, a description of maintenance practices, and an overview of appropriate diagnostic equipment and practices. An inclusion of hands-on labs/modules also aid in overall vehicle familiarization [6][7], [7]. This progression through course content need not change- only the technologies at hand will differ.

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