Global Perspectives on Electric Vehicle Education: Part II

John G. Hayes[1], Yue Cao[2], Xinmei Yuan[3], Jessica L. Suda[4], Xiaofeng Yang[5], Jens Friebe[6], Osmar Ogashawara[7], John P. Renie[8], and G.A. Goodarzi[9]

[1]School of Engineering, University College Cork, Ireland

john.hayes@ucc.ie

[2]Energy Systems Group, School of EECS, Oregon State University, USA
[3]College of Automotive Engineering, Jilin University, China
[4]Transportation Education Ctr., Department of Automotive Tech., Southern Illinois University, USA
[5]School of Electrical Engineering, Beijing Jiaotong University, China
[6]Electrical Engineering and Computer Science, Leibniz University Hannover, Germany
[7]Centro de Ciencias Exatas e de Tecnologia, Universidade Federal de Sao Carlos, Sao Paolo, Brazil
[8]Mechanical Engineering, Indiana Institute of Technology, USA
[9]US Hybrid Corp., Torrance, California, USA

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 I for the introduction to this two-paper set [1].

1 Real-world EV Projects and Electric Aviation Curriculum at Oregon State University (Y. Cao)

In recent years, many EV companies, both major brands and start-ups, have blossomed in the San Francisco Bay area. In parallel, the aviation industry is also shifting towards electrification, in the form of unmanned aerial vehicles, regional jets, and long-range aircraft, and clustering in the Seattle area. Conveniently, the state of Oregon, the home of Oregon State University, is located in the Pacific Northwest of the United States, between Washington State and California. Portland, Oregon, hosts the headquarters of Daimler Trucks, a company which envisions zero emissions in the years to come. Ironically, the rapid electromobility industry growth on the west coast has had to greatly rely on student resources from the mid-western and eastern United States regions where the majority of the high-power schools reside. Oregon State University (OSU), the flagship engineering school in Oregon, offers one of the few EV-specific curricula in the US and has graduated many to the relevant industry. Beyond the EV course, OSU also offers advanced power electronics, electric machines, motor drives, renewable energy systems, power systems and protection, and smart grids in order to provide a comprehensive education in the power and energy systems at both undergraduate and graduate levels [3].

Prior to joining OSU, Y. Cao worked in the automotive and aviation industries in Silicon Valley and Seattle. His main teaching philosophy is to bring industry practices into the classroom. Upon arrival at OSU, Dr. Cao revamped the electric vehicles course, which follows closely the Hayes textbook [2]. OSU runs on a quarter system, with only 10 weeks of course instruction, with 4 hours of lecturing per week. The content successfully covers vehicle dynamics, electric machines with a focus on permanent-magnet synchronous motors (PMSM), lithium-ion batteries and respective charging systems, and three-phase DC-AC inverters and thermal analysis.

In addition to the textbook homework problems, Cao uses several customized real-world projects to greatly benefit the students' learning. At the beginning, each student receives a unique EV brand/model from the latest years. Project 1 familiarizes students with MATLAB coding by exploring multiple drive cycles, characterizing a vehicle's rated torque, power, and speed, and plotting an acceleration curve. Project 2 dives into a PMSM's torque and speed relationships and their corresponding efficiency map. The project requests students to utilize the efficiency map to determine the vehicle's energy consumption and losses throughout a drive cycle. Project 3 models a lithium-ion battery pack which integrates with the rest of the drivetrain developed from previous projects. The battery must meet a range requirement while satisfying all the energy demands of the motor and the rest of the electric system. Finally, Project 4 requires students to model the PWM switched DC-AC inverters in Simulink/SimPowerSystems, realizing the actual power supply driving the motor terminals. It should be noted that feedback control such as field-oriented control is excluded but covered in a separate motor drives course. Throughout all four projects, students gain hands-on experience with the modelling and simulation software while understanding the entire vehicle drivetrain components and integration.

Given the strong presence of the aerospace industry in the Pacific Northwest and the emerging trend of aviation electrification, the EV course at OSU also highlights additional materials related to aviation propulsion systems. For example, these include distributed propeller-driven systems, altitude-thrust based mission profiles, high-power-density power electronics and battery packs. The OSU in-house lab assembled a complete propulsion stand for heavy-duty three-phase UAV power systems, a set-up which allows students to visually understand the propulsion mechanism and appreciate the electrification's potential impact in this industry[4][5].

2 Role and development of urban rail transit for sustainable urban transport based on industrial and academic experience (X. Yang)

2.1 Background

With ever-increasing populations, rising energy prices and environmental concerns, urban rail transit systems play more important roles for the sustainability of megacities. Rail transit has attracted much attention from both industry and academia due to the reduced congestion and CO_2 emissions. The Chinese government began to attach importance to urban rail transit in recent years, resulting in a large investment in this field. Before 2000, there were only three cities in China equipped with metro. But by the end of 2017, 34 cities in mainland China have opened urban rail transit with a total mileage of 5033 km. In addition, according to the national development plan, the total mileage of operating urban rail transit was to exceed 6000 km in the year 2020 [6].

From a world perspective, the urban rail transit has gradually developed from only one type (i.e. metro) to a diversity of metro, light rail, and tram. Some famous cities, such as New York, Paris, London, Tokyo, Beijing, and Shanghai, have owned considerable scale of urban rail infrastructure, with a network of hundreds of kilometres [7].

However, the rapid development of urban rail transit requires staff with appropriate skills. By providing intelligence and professional service, and being fully involved in many milestone events in the development of rail transit in China, Beijing Jiaotong University (BJTU) has accumulated rich on-site technical experience in urban rapid rail transit. With such industrial background, BJTU offers a complete curriculum in rail transit, which covers the basic knowledge in rail transport, organization, planning, operation and design, etc. Taking the specialised courses of the School of Electrical Engineering in BJTU as an example, the curriculum construction and implementation of such a specialty in urban rail transit is next discussed.

2.2 Curriculum Construction and Implementation

Similar to electric vehicles (EVs), electrification is essential to urban rail transit, which is also the main concern in the School of Electrical Engineering. Six main specialised courses on urban rail transit are listed as follows:

- Introduction to Rail Transit Electrification
- Rail Transit Electrical Engineering
- Urban Rail Vehicles
- Traction Power Supply of Railways
- Electric Traction Drive and Control
- High-Power Energy Conversion Technology

The abovementioned curriculum teaching of urban rail transit firstly builds a general concept of the integrated system, which covers the fundamentals of urban rail transit electrification, vehicles, power supply, power energy conversion, traction drive and control. Besides, such curricula are also designed to lay a solid foundation, broaden the vision, inspire innovation and improve international competence for students majoring in civil engineering, mechanical engineering and its automation, electrical engineering and its automation, communication engineering and other professional disciplines.

Teaching activities include in-class teaching and assignments, with the aim of improving the students' ability to analyse and solve related practical problems and their experimental capabilities. The curricula combine the theory and related applied case studies. For instance, some examples of locomotive and other rail vehicles are introduced during the course. Additionally, research projects and experiments are carried out. The purpose is to fulfil the course's practice-oriented functions, and to enhance the students' practical abilities for their future study or career.

2.3 Conclusions and Key Learnings:

- Due to worldwide rapid urbanization, the urban rail transit attracts more concern from both industry and academia.

- Multiple specialised curricula in urban rail transit are developed for meeting the requirements of staff with appropriate skills.
- A mix of electrification, vehicles, power supply, power/energy conversion, traction drive and control helps students to establish the general concept of the integrated system in urban rail transit.

3 Federal University of Sao Carlos – Brazil (O. Ogashawara)

The electrical engineering course at UFSCar began in 2009, and the pedagogy of the course is such that the content was developed from real problem situations. A report from McKinsey Company identified the electrification of transportation as a trend in the automobile industry, so it is necessary to prepare students for this new market [8]. Combining the need for the market and the pedagogy of the course, the Electric and Hybrid Vehicles discipline was created as an optional discipline open to all interested students. As a real problem situation, the modelling and simulation of the Electric Formula SAE was proposed, since UFSCar has a team that participates in this competition organized by SAE.

The team presents on how both the competition structure and the vehicle work. From this meeting, the study of electric and hybrid vehicles begins, using active learning methodologies. Project-based learning, inverted classroom, team-based learning (TBL) and conventional classes are used. In project-based learning, developed from the presentation of the UFSCar Formula Electric Team, students discuss the knowledge needed to develop the EV modelling and simulation project. This is how the content of the discipline is defined, but based on its official planning. In this definition, a correlation is constructed with the disciplines of the course and it shows how the subjects can be integrated.

The development of the project is done in teams with a maximum of 6 students, depending on the number of students enrolled in the discipline. To compose the team, the MBTI methodology is used [9] and it is also sought to form the team with students from different courses (electrical, mechanical, production, materials, etc.). The 5-step team-based learning methodology is used as follows [10]. The first is “preparation” or individual preparatory reading of previously selected text, which all students must read. The second step consists of an individual readiness assurance test. The third step is the team readiness assurance test, to answer the same assessment, but now as a team, at this time there is a great learning, as there is a discussion among the team members to choose the correct answer. Feedback is used to correct the test. Thus, students have the correction of their assessments and can add the points obtained individually and as a team. The fourth step is a small lecture clarification. The fifth step consists in team application exercise.

In 2019, there were 26 students enrolled in the discipline, divided into 7 teams. After the presentation of the UFSCar Electric Formula SAE Team, students found that they needed to study the following topics: Electrical Machines, Power Electronics, Drive Control Systems, Battery, Vehicle Dynamics and Mechanical Parts (chassis, brakes, suspension). To complete the official planning, it is necessary to study hybrid-electric vehicles. Thus, some themes and texts were chosen for the application of the TBL (4–8). The course has been implemented in 16 weeks, one week for the TBL assessment, in the following week a normal class to complement the TBL text study. Table 1 shows the content per week, the TBL text and the reference text used. In the last 4 weeks the teams develop the project and present in last week.

The modeling and simulation were developed using MATLAB & SIMULINK software. The teams search the references and videos to learn how to use the Simulink Toolboxes.

The assessment modes were TBL assessment, individual test and the project. Only one student failed, 23% with grade > 8.0, 46% with 7.0 < grade <8.0 and 27% with 6.0 < grade < 7.0. These results and the projects presented by the teams show the successful outcome of these applied methodologies.

Table I – Course content by week

week	Contents	TBL text	Reference
1	Course presentation and introduction		
2	TBL1 - Architecture of Hybrid Electric Vehicle	[11]	
3	Topics in Architecture of Hybrid Electric Vehicle		[16][17]
4	TBL2 – Electric Machines	[12]	
5	Topics in Electric Machines		[2]
6	TBL3 – Power Converter	[13]	
7	Topics in Power electronics		[2]
8	TBL4 – Modeling and simulation	[14]	
9	Introduction to Vehicle Dynamics		[2][17]
10	TBL5 – Battery	[15]	
11	Topics in Batteries		[2]
12	Chassis, brake system and suspension		[17]
13	Project – modeling and simulation		[18]
14	Project – modeling and simulation		
15	Project – modeling and simulation		
16	Project presentation and conclusion		

4. Electric Vehicles and Energy Transition within University Education at the Leibniz University Hannover (J. Friebe)

4.1 Background

The Gottfried Wilhelm Leibniz University Hannover (LUH) was founded in 1831 in Hannover, Lower Saxony, Germany. It is a technical university (TU) and part of the German TU9, an alliance of leading technical universities in Germany. Currently, the University has approx. 30,000 students, approx. 3,000 researchers, 9 faculties, and more than 180 institutes. In 2018, the University was able to acquire more than 120 million Euro in third-party funding and had partnerships with 167 Universities worldwide [19]. The Institute of Drive Systems and Power Electronics, as one of the Institutes of the faculty of Electrical Engineering and Computer Science, has a strong traditional connection to automotive, industrial drives and renewable energy research and industry. The merging of Drives Systems and Power Electronics (IAL) into a joint institute reflects the technological development towards integrated systems, especially in the fields of automotive, industrial drives, renewables (especially wind) and also the electrification of aircrafts for more and all electric aircrafts. Additionally, the Power Electronics Group has also a strong focus on Microgrids, Modular-Multilevel-Converter and Photovoltaic Converter [20]. Due to the funding structure in Germany, typically joint projects of university and industry partners are applied for at funding calls from national ministries. These projects are often organized or coordinated by regional partners, even if it is not a must. Figure 1 shows the location of some of the companies working in the field of automotive and renewable energies and having a cooperation with the IAL within former or current projects. It can be seen that there is a strong accumulation of regional partners as well as an accumulation around automotive manufacturers and industrial centers. Figure 2 shows an example of a drivetrain of a public funded project.

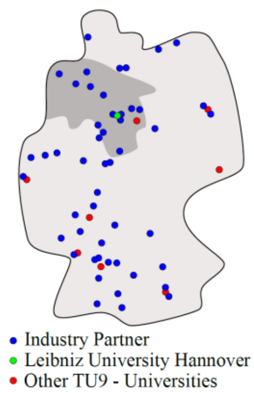

Figure 1: Location of the Leibniz University Hannover, Industry Partner and the other TU9-Universities in Germany. The federal state Lower Saxony is highlighted in grey.

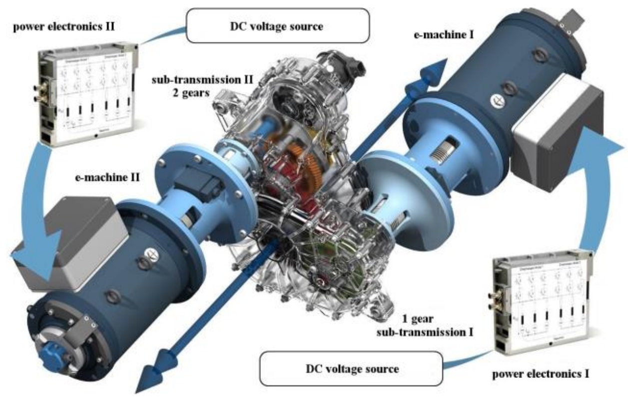

Figure 2: Drivetrain of the Speed2E Project, covering speed of up to 30,000 rpm for two sub transmissions [21]

1.2 Teaching and Research

The teaching within the context of automotive and energy transition is mainly covered within courses offered in the Bachelor and Master Programmes for Electrical Engineering and Information Technology, Power Engineering, Mechatronics and also within two English-language Master's Programs Energy Technology and International Mechatronics. The students are given mainly fundamental mandatory lectures within the first four semesters of the bachelor programs but a high freedom in later semesters, and especially in the master programs. This gives the opportunity for a very individual focus in the area of automotive and energy transition topics. The idea behind this structure is to create strong foundations in engineering education to enable students to work in interdisciplinary teams. The automotive and energy transition related lectures are starting with "Basics of Electromagnetic Power Conversion", followed by lectures in the fields of drives and power electronics, as shown in Fig. 3.

A benefit of the third-party funding structures in Germany accompanied by the high degree of freedom for the students in 5th and 6th bachelor semesters and in the master semesters is the possibility for student employments (typically up to 40 h/month) within research projects at the institutes. Based on this there is the opportunity within the education to enthuse the students for scientific topics of research projects. With this strong connection between the institute and students after up to two semesters in the Bachelor's and up to four Semesters in Master's, there is often the possibility for an employment as "Research Associate". Therefore, the research associates are strongly connected to actual research within industry while also having the benefit of a university employment setup with a high degree of freedom within their own research activities leading to their PhD after typically around five years. While missing the system aspects, as mentioned especially in this paper set, an industrial applications lecture series is offered. This lecture series includes presentations from alumni of the IAL and from experts on specific topics covering system aspects which are not part of the curricula, e.g. on electric vehicles from German car manufacturers.

4.3 Comparison with the programs discussed by the other authors contributing to this paper

The main difference with the other universities in this paper set is the missing focus on electrical vehicles as a system within the curricula at the Leibniz University Hannover. Instead, students can decide on their specific topics as parts of their curriculum on their own. For helping them finding their individual focus, the industrial applications lecture series is offered to all students, either undergraduate or graduate. The difference to other universities might also be based on the specific background of the industry in Germany being very much focused on automotive applications. German students often have a broad overview of automotive systems and their electrification, and their wish to work on certain topics in the automotive field can easily be addressed through student employment and internships parallel to their studies. Nevertheless, having more than 50% international students in masters in electrical engineering in the last years, and numbers still increasing, the situation is changing fundamentally [19]. Therefore, there are already drafts in preparation for examples of curricula within the field of automotive and energy transition, to help the students in their decision to pick the right lectures if they plan to work within the respective field. Here the experience and examples from other universities discussed in this paper will be quite useful.

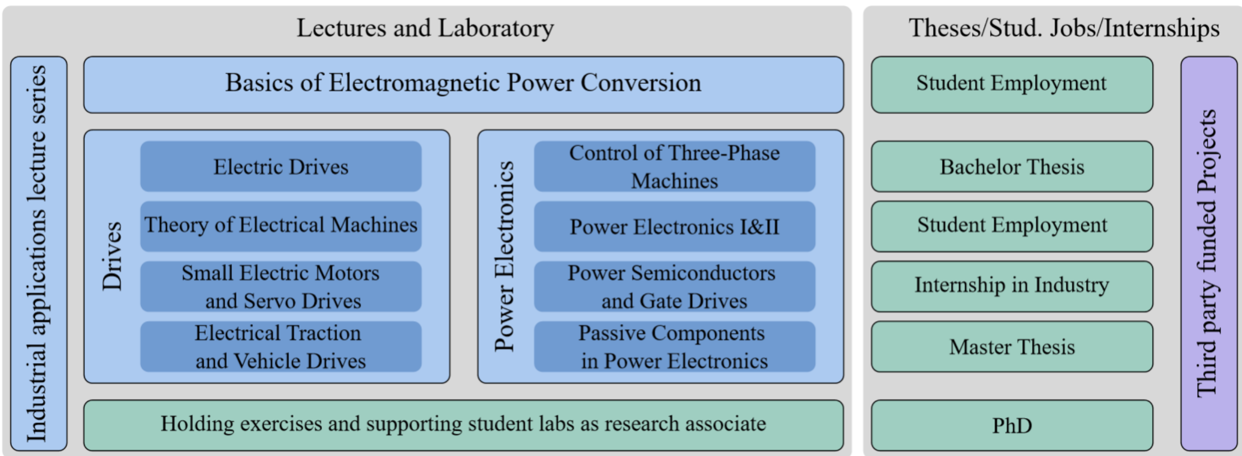

Figure 3: Lectures, laboratories, theses, job opportunities and internships within the electric vehicle education at Leibniz University Hannover.

4 Conclusion

With the significant shift towards electromobility within the transportation industry, educators from around the world are transforming curricula from the former focus on the internal combustion engine to that of the electric powertrain. The integration and interconnection of related content that enables these modernized vehicles to operate, such as energy storage, power electronics, and electric machines, comes as no small challenge. Due to frequent advancements in vehicle hardware and software technology, curricula require continuous updating. Additionally, the sustainability of greener technologies and their environmental impacts are becoming an important topic of discussion in the classroom. Strategically adapting and updating this curriculum will ensure that students are prepared to work in the reshaped transportation industry of the future.

References

[1] Hayes, J.G., Cao, Y., Yuan, X., Suda, J.L., Yang, X., Friebe, J., Ogashawara, O., Renie, J.P., Sullivan, C.R., Goodarzi, G.A., “Global Perspectives on Electric Vehicle Education: Part I”, EEDS 2020.

[2] Hayes, J.G., Goodarzi, G.A., *Electric Powertrain Energy Systems, Power Electronics and Drives for Hybrid, Electric and Fuel Cell Vehicles*, ISBN: 978-1-119-06364-3, 1st edition, John Wiley & Sons, January 2018, 2nd Print October 2019.

[3] T. Kilgore, A. Thurlbeck, Y. Cao, T. Brekken, C. Li, P. T. Krein “PowerBox: A Modern Power Electronics Education Toolbox Using Si and SiC Devices,” in *Proc. IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2020, pp. 1-6.

[4] A. Thurlbeck and Y. Cao, “Analysis and modeling of UAV power system architectures,” in *Proc. IEEE Transportation Electrification Conf. (ITEC)*, 2019, pp. 1-8.

[5] Y. Cao and A. Thurlbeck, “Heavy-duty UAV Electric Propulsion Architectures and Multi-timescale Multi-physics Modeling,” in *Proc. AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, 2019, pp. 1-13.

[6] Zhang, D., Jiao, J., "How Does Urban Rail Transit Influence Residential Property Values? Evidence from An Emerging Chinese Megacity," *Sustainability-Basel*, 2019, 11(2), pp. 534.

[7] Li, W., "Development of a vocational college course on metro service telephone communication system maintenance based on work process," *World Transactions on Engineering and Technology Education*, 2014, 12(2), pp. 289-293.

[8] Knupfer, S.M. et al. *Electrifying insights: How automakers can drive electrified vehicle sales and profitability*, McKinsey & Company, 2017.

[9] Myers, Briggs. *Introduction to type: a guide to understanding your results on MBTI instrument*, CPP, Inc., 1998.

[10] Najdanovic-Visak, Vesna. “Team-based learning for first year engineering students,” *Education for Chemical Engineers Journal*, Elsevier, 2016.

[11] Chan, C.C. “The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles,” *Proceedings of IEEE*, vol. 35, n.4, April, 2007.

[12] Zhu, Z.Q., Rowe, David. “Electrical Machines and Drives for Electric, Hybrid, and Fuel Cell Vehicles,” *Proceedings of IEEE*, vol. 35, n.4, April, 2007.

[13] Lai, J.S., Nelson, D.J. Energy “Management Power Converters in Hybrid Electric and Fuel Cell Vehicles,” *Proceedings of IEEE*, vol. 35, n.4, April, 2007.

[14] Gao, D.W., Mi, C., Emadi, A. *Modeling and Simulation of Electric and Hybrid Vehicles*. *Proceedings of IEEE*, vol. 35, n.4, April, 2007.

[15] Burke, A.F., “Batteries and Ultracapacitors for Electric, Hybrid, and Fuel Cell Vehicles,” *Proceedings of IEEE*, vol. 35, n.4, April, 2007.

[16] Ehsani, M., Gao, Y, Longo, S., Ebrahimi, K.M. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 3rd Edition, CRC Press, 2018.

[17] Khajepour, A., Fallah, S., Goodarzi, A. *Electric and hybrid vehicles: a mechatronic approach*. John Wiley & Sons, 2014.

[18] Miller, S. Hybrid Electric Vehicle Modeling and Simulation: https://www.mathworks.com/videos/hybrid-electric-vehicle-modeling-and-simulation-81751.html?s_tid=srchtitle

[19] Leibniz Universität Hannover, Zahlenspiegel 2019.

[20] Institut für Antriebssysteme und Leistungselektronik (IAL), *Institute Report* 2017/2018/2019.

[21] Project “Speed4e“, http://www.speed4e.de/Joomla/index.php/en/, accessed 04.03.2020.