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Advancing Automotive Electronics: The Role of Collaborative Education and Project Development

To respond to the ever-increasing requirements of automotive electronics, universities need to adapt and play an active role in creating new research environment and provide proper education to the young generation which will face challenging tasks in this rapidly developed field. Vehicular technology education is crucial for the next generation of automotive electronics developers and engineers. Several education models, such as problem-and-project based learning, academic-academic collaboration, and academic-industry collaboration, are highlighted as successful examples.

Demand of Future Vehicle Society

We are living in an interesting period of human history, marked by a transition towards a more sustainable mobility system through the introduction of electric vehicles (EVs) and electric aerial vehicles (EAVs) [1]. Fig. 1 shows a vision of Japan's future e-mobility society, which requires the development of various cutting-edge automotive electronics technologies, such as dynamic wireless power transfer, operation management system, and autonomous driving [2]. Thus, automotive electronics has become a melting pot of various fields, and it can be seen as an ideal

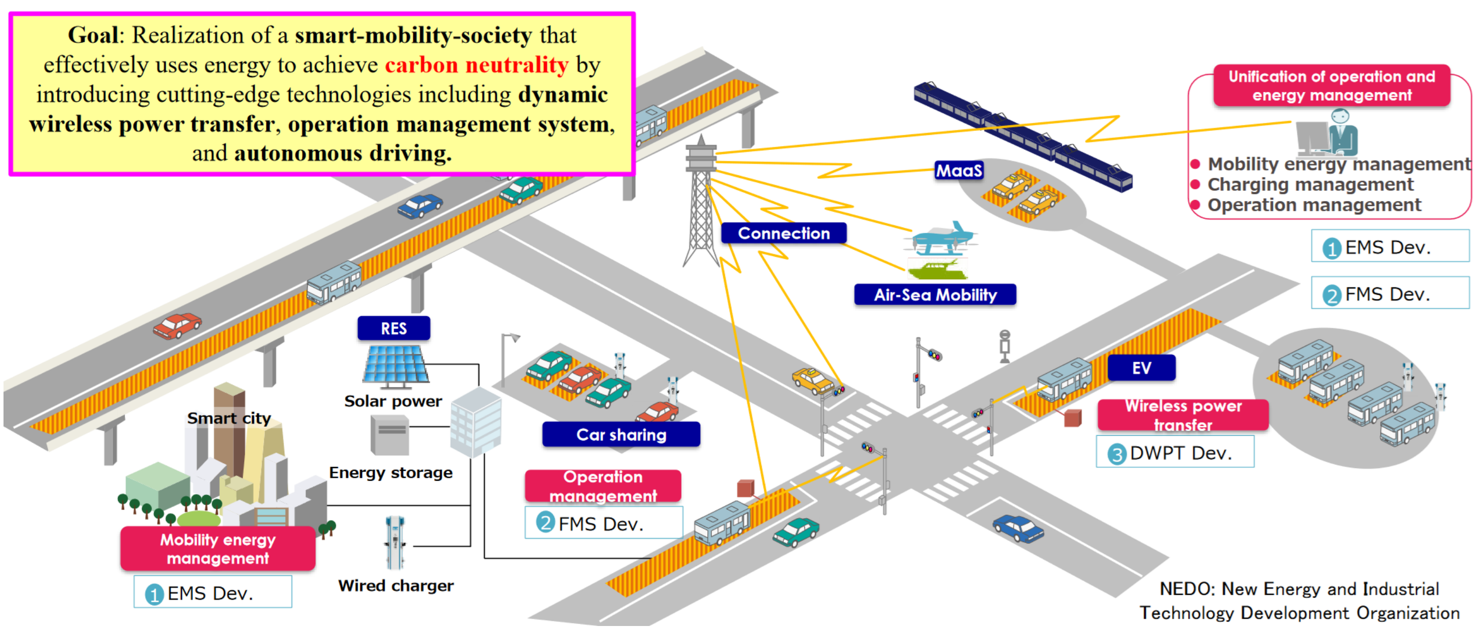

Figure 1. A vision of Japan's vehicle society in 2050s (Source: https://www.nedo.go.jp/, , used with permission).

specimen of transdisciplinary research and development. In this century, the foundation of automotive electronics encompasses diverse fields such as power electronics, power devices, materials, physics, antennas, automotive engineering, mechatronics, aerospace engineering, sensors, communication technologies, computer science, data science, control theory, economics, human health science and law. The collaboration between researchers and engineers from these various disciplines has fostered significant advancements and innovations. Consequently, many new issues arise in advancing automotive electronics to realize the future vehicle society. Almost of them are transdisciplinary issues. An example is the integration of wireless power transfer system and onboard sensor system for estimating the relative position between the vehicle and the coils installed in the road. Another example is the integration of unmanned aerial vehicle motion control and power electronic control for optimizing the transmission efficiency of inflight dynamic charging. The mobility system is a huge system of multi-agents with both global and local objectives. Thus, strategies to optimal energy management should be answered by the knowledge of multi-agent system theory, big data, machine learning, energy storage, and renewable power system. The integration and collaboration between EVs and EAVs are an emerging area of interest.

We need skilled individuals to overcome the challenges. As the journalist Bob Schieffer once said, "*it's getting the right person that's the challenge*," there is a growing need for researchers and engineers with adequate skills that can effectively respond to the demands of vehicular technology. Therefore, enhancing automotive electronics education becomes an essential task for not only the universities but also the companies. **This raises a crucial question: How do we shape the new education model?**

Requirements of Automotive Education

There is usually a gap between the society's demand and the current education and research model. The involving subjects of the future e-mobility have been independently taught and studied in different departments, faculties, and laboratories. For instance, machine learning, automotive engineering, control theory, and economics are usually the subjects of the different departments in any university. We can easily find an expert in each of the aforementioned fields. Unfortunately, finding individuals who can work across the boundaries of different academic fields is not easy. Considering the above discussion, it is essential to establish new education models that push the boundaries of existing research and education. These models should gather and synthesize knowledge and technologies that have traditionally been studied separately in each academic field. It is expected that the new educational model will:

(1) Provide the students with opportunities to create new academic disciplines through transdisciplinary approaches.

(2) Support the students courageously tackle the challenges that humans face in not only e-mobility but also other aspects of the future society.

(3) Nurture the students to be global citizens with transdisciplinary perspectives, advanced problem solving, and strong motivation to respond to demands and changes in modern world.

It should be noted that merely gathering the individualized knowledge is not sufficient to solve multifaceted and complex problems. We need a radical modification of the current educational system, buck the trend to segment and take the responsibility of diversifying knowledge in a new way.

Education through Collaboration

"*All for one and one for all, united we stand divided we fall*." The merits of collaboration have been well understood throughout human history. In a company, working collaboratively helps improving productivity and gives all members a sense of purpose in the organization. It also becomes easier to brainstorm the complex problems which requires different expertise. In a school, collaborative education (CE) is an approach to teaching and learning that involves groups of students to solve a problem or to complete a project. In general, the benefits of CE are as summarized as follows [3]:

<u>Social benefit:</u> CE helps to develop a social support system for students. CE also leads to increased understanding of diversity

Term organization with basic project

Weeks	1- 2	3-4	5-6	7-8	9-10	11-12	13	14-15
	PBL-unit 1	PBL-unit 2	PBL-unit 3	PBL-unit 4	PBL-unit 5	PBL-unit 6		Final Assessment
Project	Meeting 1-2	Meeting 3-4	Meeting 5-6	Meeting 7-8	Meeting 9-10	Meeting 11-12		Presentations

Term organization with more substantial and complex project

Weeks	1- 2	3-4	5-6	7-8	9-10	11-12	13	14-15
	PBL-unit 1	PBL-unit 2		PBL-unit 3		PBL-unit 4		Final Assessment
Project	Meeting 1-2	Meeting 3-4	Meeting 5-6	Meeting 7-8	Meeting 9-10	Meeting 11-12		Presentations

Figure 2. Term organization in project- and problem-based learning (PPBL) [4] (Source: e-TESC Lab, University of Sherbrooke, used with permission).

among students and staffs. Furthermore, it creates a positive atmosphere for modelling and practicing cooperation and develops learning communities.

Psychological benefit: CE develops positive attitudes. It allows student-centered strategy that increases students' self-esteem. Additionally, cooperation reduces anxiety.

Academic benefit: CE promotes critical thinking skills and involves students in the learning process. It models appropriate student problem solving techniques, and it is helpful in motivating students in specific curriculum.

Assessment benefit: CE utilizes a variety of assessments.

Three CE Models to Advance the Automotive Electronics Education

Motivated by the above basic benefits, the scale and concept of CE can be extended beyond the boundaries of a company, a school, a country, and a continent, to tackle the new challenges in automotive electronics. To demonstrate this idea, this article will examine three CE models, namely, problem-and project-based learning (PPBL), hierarchically decentralized collaborative education (HDCE) and university social collaborative education (USCE).

PPBL model

Since the last decade, PPBL has been implemented by many universities worldwide. For instance, the University of Sherbrooke developed a PPBL (in French: *Apprentissage par problemes et par projets en ingénierie, APPI*) [4]. This PPBL model is based on two pillars: "Knowledge via Competencies," and "Project based learning units" (PUB-units).

Knowledge via Competencies: A competency is not merely the ability to execute a given procedure, it requires rather the ability to adapt to various situations to solve a category of problems for realizing nontrivial tasks. In the PPBL framework, competencies can be classified in four categories: engineering and scientific, design, interpersonal, and intrapersonal competencies. Knowledge acquisition becomes a means for reaching the objective of developing competencies. Three types of knowledge can be acquired:

- Declarative knowledge: The fact to know factual information, such as a definition, a hypothesis, or an algorithm.
- Procedural knowledge: How to use factual information, for instance, the ability to execute repetitive tasks.
- Conditional knowledge: Know when and where to use factual information, for instance, the ability to select appropriate resolution methods.

PBL-units: The educational program is organized by the integration of academic terms and industrial training terms. Each academic term is based on a theme, such as computer system architecture, electrical and electronic system, control and automation, etc. Each term contains two types of activities: several consecutive two-week PBL-units, and a design project which spread over the whole term. A typical example of term organization is shown in Fig. 2. As the "basic step" of the learning progress, the PBL-unit is to develop one or several given competencies. To this end, the resolution of the problem should be carefully designed. It must be sufficiently "complex" to encourage students to the development of the targeted competencies. On the other hand, it must also be sufficiently "simple" so that the resolution

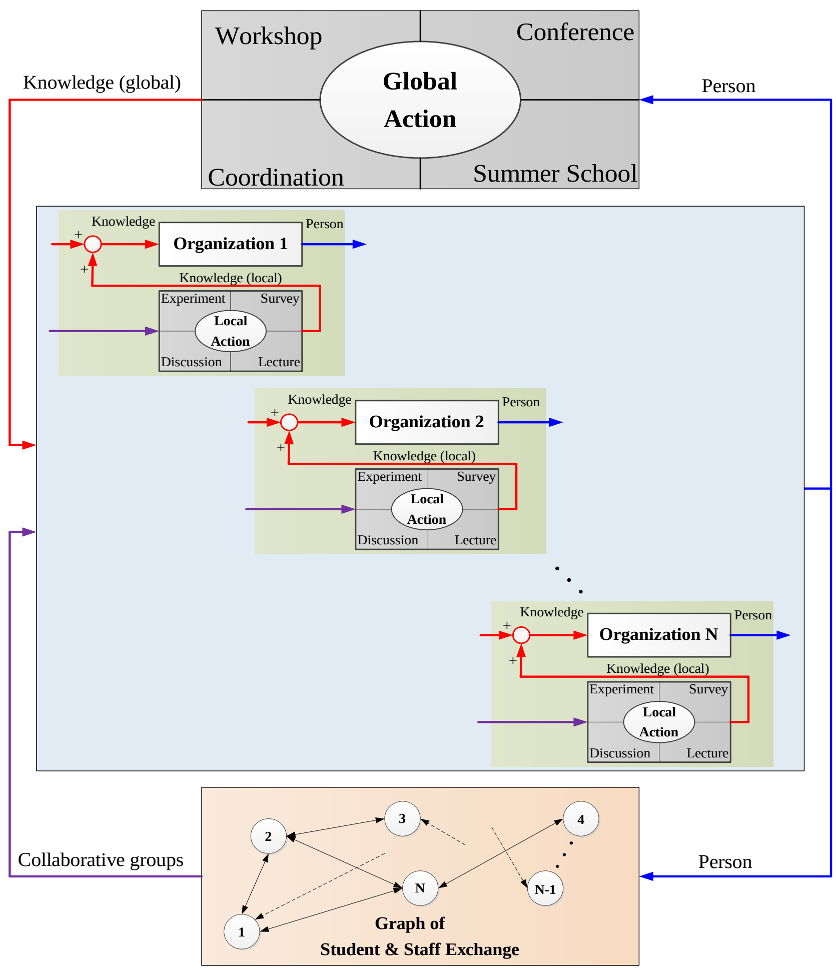

Figure 3. A model of hierarchically decentralized collaborative education (HDCE).

can completed in less than 2 weeks. The problem must correspond to a real engineering situation. It is formulated so that students can do the exercise of identifying the essential skills and knowledge necessary for solving the problem.

In the following sense, the PPBL model satisfies the requirements (1) ~ (3) of automotive electronics education:

(1) In the PPBL model, knowledge acquisition is just a means to develop targeted competencies. This allows the students a certain level of complexity to learn and utilize knowledge from multiple disciplines to solve the problem.

(2) The PPBL approach makes the students more responsible and autonomous in the learning process. Professors help the students to find solutions by providing opinions or indications, validating or invalidating solutions, but never providing a solution directly.

(3) The PPBL is commonly an international environment where individual student can learn by collaborating with other students, professors, and industrial experts.

HDCE model

Fig. 3 describes the HDCE of N organizations (partners). Everyone is expected to have its own strength and expertise, which are commonly different to the others. The partners share one (or several) sources of funding to establish a graph (network) of student and staff exchange. The research funding aims to carry out a large project that tackles a complex research goal which cannot be achieved by a single partner.

The partners sign an agreement such that for some $k, q \in [1, N]$, organization-k accepts some certain people from organization-q to be the visiting researchers for a certain period. By this way, they can organize the collaborative group that includes the person from the host university and the visiting researchers. Focusing on a sub-goal of the main project, the collaborative group conducts joint study using the research facilities provided by the host university. To achieve the sub-goal and create new knowledge, the collaborative group is expected to perform various "local actions" in the host organizations. Typical local actions are discussion, doing survey, conducting experiment, giving lecture, and submitting academic papers, etc.

New knowledge is also created and distributed via the "global action" that involves all partners. The global actions can include scientific event organizations, such as conferences and workshops to present and discuss the outcome of the collaborative work; summer or winter schools on vehicle technology for students and young researcher and partner staffs; general assembly for the management of funding and coordination of programs.

Transparently, the HDCE model in Fig. 2 satisfies the requirements (1) ~ (3) of automotive electronics education:

(1) The HDCE provides the students and staffs with the opportunities to learn other disciplines that might not be taught in their organization.

(2) The HDCE can support students and staffs the opportunity to be advised by excellent researchers and experts from different fields. This motivated them to bravely tackle the real challenges of e-mobility and automotive technology of this century.

(3) The HDCE allows students and staffs to collaborate with people from different countries and cultures. They can thus practice foreign languages and learn to communicate effectively as global citizens. Furthermore, students and staffs can learn transdisciplinary approaches as well as critical thinking and problem-solving skills by participating into a true transdisciplinary project.

USCE model

Fig. 4 describes the USCE model that involves a university and one or several industrial companies. To create new knowledge and technologies desired by the society, both parties sign a contract to establish a collaborative education and research program. The contract defines the contribution of each side, such as research funding, salary budget, equipment, and devices. The university provides the lecturers as well as the researchers and students to collaborate with the company's engineers and experts. In some situations, the company's expert might take a position as an adjunct professor at the university. To thoroughly learn from the academic side, some companies send their engineers to university to become full-time students. It is possible that the company provide the salary

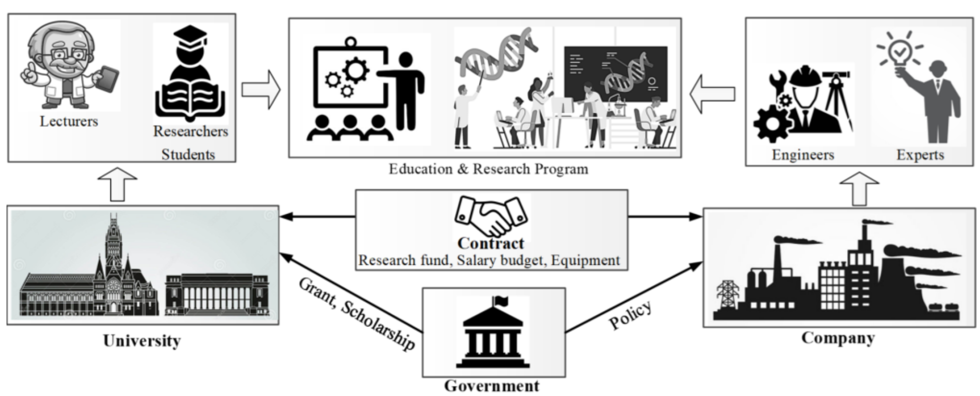

Figure 4. A model of university social collaborative education (USCE).

budget such that the university can open some contracted/specially appointed professor positions and/or postdoc fellow positions. Besides, the government is expected to support both sides by providing research grants, student scholarships, law, and policies.

The USCE model in Fig. 3 also satisfies the requirements (1) ~ (3) of automotive electronics education:

(1) The USCE provides students with opportunities to acquire knowledge that is barely taught by the university. The students can utilize the special vehicle testing facilities which, in almost all cases, are not available at the university's laboratories.

(2) The USCE helps students solve problems that society actually needs. This ignites the fire of social responsibilities in their hearts, as they clearly understand the practical applications of their research outcomes.

(3) By working with the engineers and experts from company, students can learn the skills essential for their future career, such as teamwork and real-world problem solving. The closer industrial knowledge will facilitate their transitions from academic to the professional sphere. It can be expected that as students graduate, they will easily get used to the company's working environment and grow up quickly.

In the following Sections, this article examines several examples of the PPBL, HDCE and USCE models.

Example 1: HESU Project

This section introduces a PPBL project named HESU: Eco-Drive Platform (HESU for Hybrid Energy System Unit), which addresses electric vehicles and is a multidisciplinary initiative. HESU was performed in 2018 at the Department of Electrical and Computer Engineering (University of Sherbrooke). The project was to develop a suitable methodology that helps EV drivers to optimize their energy consumption and maximize the lifetime of the battery pack [5].

The goal of the project can be presented by a simple sentence: How to improve the energy consumption and battery lifetime of an EV by developing software (SW) and hardware (HW), to define the optimal speed over the selected routes and smooth the current demanded to the battery using supercapacitor (SC). According to the system architecture shown in Fig. 5, there are three main blocks:

- Simulator is the central of the project.
- HESU is the electrical part: batteries, SCs, DC/DC converter, motor drives.
- Eco-driver is all the HW and SW, that can be divided in the eco-drive server and control HW in the EV.

Transparently, this was a transdisciplinary project involving computer engineering, communications protocols, cloud computing, web data logging, PCB design, micro controller programming, power sources, power electronics and simulations. To perform the project, a team was organized including 9 students: 4 computer engineering students were dedicated to the eco-drive system tasks, with the support of 2 electrical engineering students who developed the energy vehicle model for simulation. The remaining 3 electrical engineering students were devoted to the HW parts and integration with the simulations. The team utilized Scrum, which is an implementation of Agile, for the project management method.

The project was performed in the seventh and eighth terms. The most important achievement of the project is the enhancement of student learning skill. In many cases, the team needs to collect the previous learning knowledge and acquire new learning to solve the problems by themselves. For instance:

- In the third term, the student had PBL-units on electrotechnics where they learned how to manipulate and measure batteries and SCs. In the HESU, the students had to combine the previous learnings with the new learning of battery and SC design.

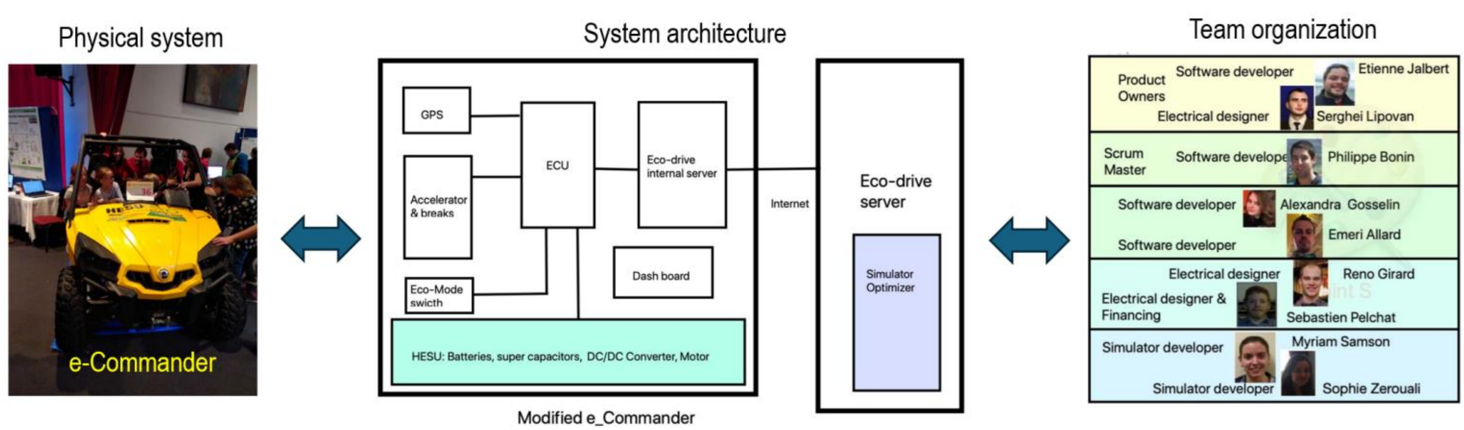

Figure 5. Transdisciplinary strategy of the PPBL project HESU [5] (source: e-TESC Lab, University of Sherbrooke, used with permission).

- In the fifth term, the students had PBL-units on embedded systems where they learned how to control a system using micro-controllers. In HESU, the students had to use previous learnings to design a system including several processors, each assigned to a special task.
- In the sixth term, the students had PBL-units on web development. In HESU, they had to use these learnings and acquire new learning, such as the use of Google Maps API and a connection of the simulator to a website.

All students in Fig. 5 graduated at the end of the project, and shortly afterwards found good engineering positions.

Example 2: OWHEEL Project

Starting from 2020, OWHEEL is a 4-year Marie Skłodowska-Curie Actions RISE project [6]. To advance the automotive technology, the project focuses on a disruptive engineering of alternative vehicle chassis concepts for future automated driving mobility. The project covers development, industrial implementation and testing of innovative wheel corners for electric vehicles having automation level 4 to 5 in accordance with SAE J3016 standard.

The OWHEEL project is based on intensive student and staff exchange that leads to collaborative education and research between ten partners from six European countries, Japan and South Africa are listed as follows: 1) Tenneco Automotive Europe BVBA (TEN, Belgium); 2) Arrival Ltd. (ARRIVAL, UK); 3) Technische Universiteit Delft (TUD, Netherlands); 4) Università degli studi di Modena e Reggio Emilia (UNIMORE, Italy). 5) Technische Universität Ilmenau (TUIL, Germany). 6) Università degli Studi di Napoli Federico II (UNINA, Italy). 7) University of Surrey (USR, UK). 8) Vilniaus Gedimino Technikos Universitetas (VGTU, Lithuania); 9) University of Tokyo (UT, Japan); 10) University of Pretoria (UP, South Africa). Recently, the consortium has been extended with Politecnico di Torino and Megaride company from Italy. They are replaced activities of the Arrival.

As shown in Fig. 6, each partner has its own strength and experience. For instance, TEN, as a world-leading original equipment manufacturer of chassis systems and components, will train students and staffs from academic participants in advanced chassis design. VGTU researchers have a cross-disciplinary knowledge through involvement both of Vehicle Dynamics and Artificial Intelligence. UT will train visiting students in modern control engineering technologies with particular focus given on electric vehicle mechatronic systems. This diversity makes it possible to achieve "local action" of knowledge creating and sharing through a people-centric approach. Through secondments, seconded students collect theoretical and practical experience gained from new research, technological and cultural environments. They learn the transdisciplinary approaches from various collaborations, such as:

- Develop vehicle, sub-systems and tire models (TUIL, UP), and form the consortium software chain for further software- and hardware-in-the-loop testing conducted by USR, VGTU, TEN and ARRIVAL as well as driving simulator performed by TUD.
- The results of driving comfort assessment and ride quality studies, which are based on the analysis of driving simulator (TUD) and proving ground (UP) experiments, will be transferred to USR and UNINA for the ride comfort controllers that then will be implemented by TEN in active wheel corner prototypes.
- The developed driving comfort and ride quality criteria (TUD, UP, TEN), will be transferred to VGTU for the development of mathematical model of passive wheel corner design, including light weighting solutions (UNI-MORE), results will be implemented by TEN in proof of the concept [7].

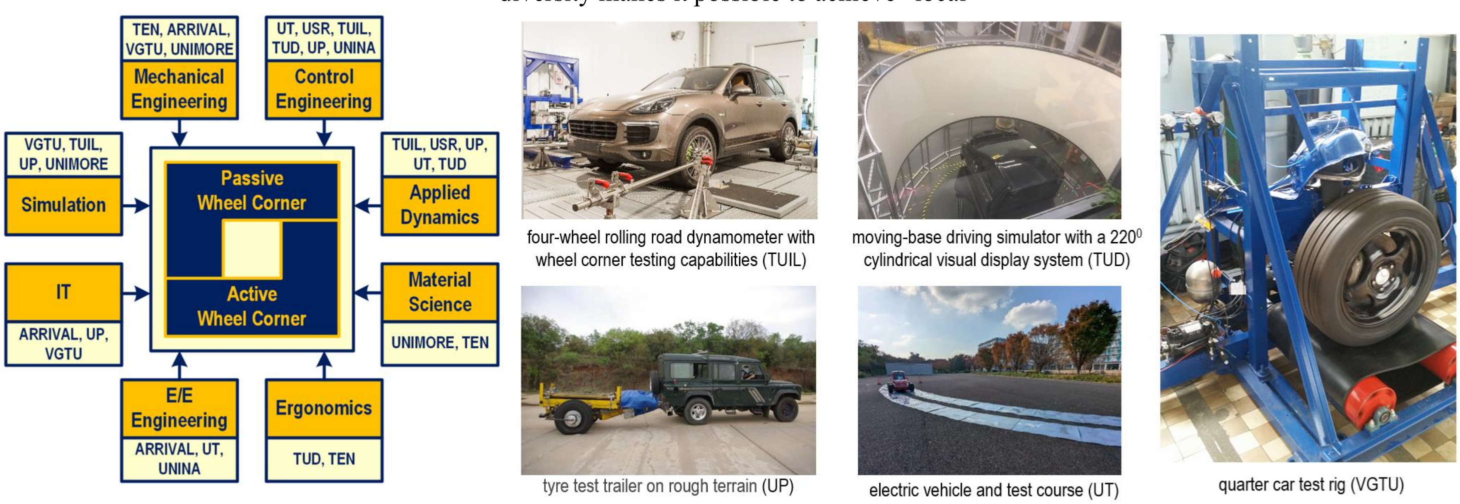

Figure 6. Multi-disciplines and multi-experimental facilities integrated in OWHEEL (Source: https://0-wheel.eu, used with permission of OWHEEL partners).

- New coordinated control techniques for active wheel corner (TUD, TUIL, USR) will be evaluated in the combination with vehicle state observers (UT, UP) and later experimentally evaluation using electric vehicle platform [8].

Students are also trained by submitting the outcomes of their work to highly reputable journals in the field of vehicle design, automated driving, and automotive control systems.

Notably, most of OWHEEL principal investigators and supervisors are involved into technical and standard committees of various professional societies, such as IEEE. These channels are used for organization of special OWHEEL sessions at different scientific events. Consequently, the students and staff involved in the OWHEEL project have been trained through various "global actions":

- 2020-2024: Annual conferences of International Society of Terrain-Vehicle Systems (responsibility: UP).

- 2022-2024: SAE WCX Congress (responsibility: VGTU, TUIL).

- 2021-2024: organization of OWHEEL Special Session at dedicated conferences of IEEE Industrial Electronic Society (UT, TUIL).

To conclude the OWHEEL and prepare for the next a Marie Skłodowska-Curie Actions RISE project on advanced automotive control, a workshop was held at University of Technology of Compiegne (UTC, France) [9]. This is the workshop on "Modelling, Control, Navigation of Electrical Multi-actuated Vehicles." Many students and staffs from OWHEEL partners and other universities participated in the workshop to engage in interactive, multidisciplinary discussions on multi-actuated vehicles.

By combining many universities and industrial organizations, OWHEEL is certainly a typical example of the HDCE in Fig. 3. It has created a robust strategy for education, research, and knowledge sharing with the use of versatile and optimized tools to bring benefits to both participating individuals and the whole consortium, thus advancing automotive electronics and vehicular technology. As shown in Fig. 7, OWHEEL enhances the international friendship between young students. The melting pot of OWHEEL contributes to the society the highly skilled worker. For instance, Mr. Takumi Ueno, who actively collaborated with seconded students from TUIL and UTC [10], has received the Dean's Award for excellent Master Thesis at Department of Advanced Energy (UT).

UT students discuss with Prof. Valentin Ivanov (TUIL) on vehicle dynamic control

Mrs. Leila Gharavi (seconded student from TUD) introduces her research to UT undergraduate students

Mr. Takumi Ueno receives Dean's Award for his Master Thesis on driving force control of electric vehicles

Mr. Viktar and Mrs. Aleksandra Beliautsou (seconded students from TUIL) conduct drone-to-vehicle integration experiment at UT

OWHEEL workshop "Modelling, Control, and Navigation of Electrical Multi-actuated Vehicles," (March 2024).

UT students listen to the lecture on state estimation and advanced motion control of vehicle given by Prof. Alessandro Victorino (UTC)

Figure 7. Collaborative activities for the promotion of student's skill under the support of OWHEEL project (Source: https://o-wheel.eu/, used with permission).

Example 3: PANDA Project

PANDA (**P**owerful **A**dvanced **N**-level **D**igital **A**rchitecture for electrified vehicles and components) was funded by the European Commission in the Research and Innovation Action [11]. It started in December 2018, and has run for 4 years. Coordinated by Prof. Alain Bouscayrol (University of Lille), the PANDA project involved 11 organizations from 7 EU countries (University of Lille, Siemens, Valeo, Technical University of Cluj-Napoca, Typhoon HIL, Uniresearch, Renault Group, Bluways, TUV SUD, The Universite de Bourgogne Franche-Comte (UBFC), and Vrije Universiteit Brussel (VUB). Traditional manufacturers of internal combustion engines (ICEs) develop and assemble engines and transmissions independently form car manufacturers. However, the development is different in electrified powertrains, as it is more complex to integrate all electrified systems in the vehicle design. Thus, an essential issue is the reduction of development time (time-to-market) through standardization of the model/simulation. The main goal of PANDA was to provide the unified organizations of digital models for seamless integration in virtual and real testing of all types of electrified vehicles and their components. To achieve this goal, PANDA was organized using the HDCE model as shown in Fig. 3. However, PANDA has some special strategies and philosophies which distinguish it from OWHEEL and other projects of the same level.

In order to generate the "local actions" of education and training, the PANDA project has two main strategies, as shown in Fig. 8.

- First, PANDA shares among the partners its fundamental innovation of Energetic Macroscopic Representation (EMR) formalism [12]. EMR is a method to organize models of energetic systems (such as motors, converter, batteries and other electrical components). Instead of using structural models to represent components, EMR uses the power flow between components as central aspect of the modelling. The EMR formalism has been used as a standard organization of the models to respect this natural causality, to highlight the power flows between subsystems, and to systematically deduce control organization of the different vehicles. The EMR is taught in graduate level at not only French universities but also many universities worldwide: *Université du Québec à Trois-Rivières* and University of Sherbrooke (Canada), Harbin Institute of Technology (China), Hanoi University of Sciences and Technology (Vietnam), INESC Coimbra (Portugal), etc.
- Second, PANDA accelerates the development process by adding a virtual validation axis and re-arranging the V-Model to a W-Model. The main idea is to maximize the virtual testing using an innovative simulation architecture in an open general framework for virtual and real testing of the products.

Based on the EMR and the W-model, the partners conducted various local studies (DC/DC converter control, Battery management, Electric powertrain control, Electric motor control, etc.) using different types of electric vehicles (battery electric vehicle by Renault, fuel cell vehicle from European project MobiPOST, plug-in hybrid electric vehicle by Valeo, etc.). A cloud simulation platform was established with EMR library and computing facilities. The cloud platform was effectively utilized for fast sharing models and knowledges between partners

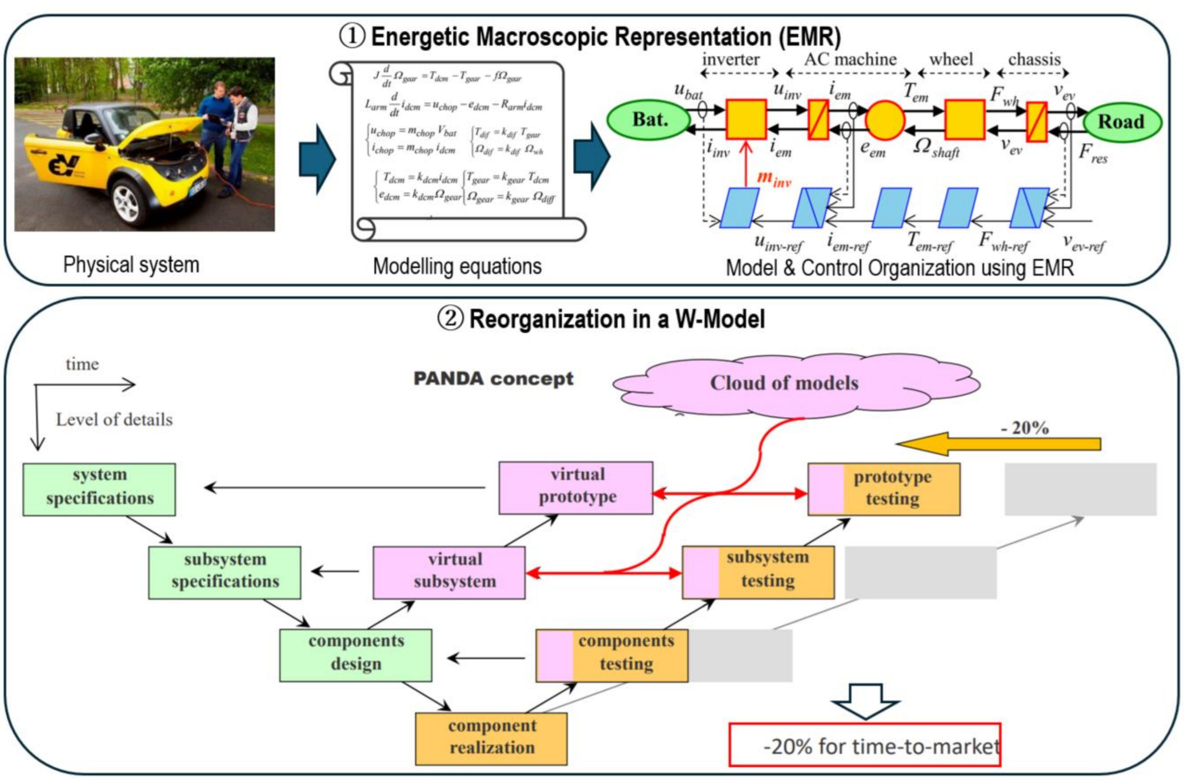

Figure 8. Two main strategies of PANDA project: EMR and W-Model (Source: https://project-panda.eu, used with permission).

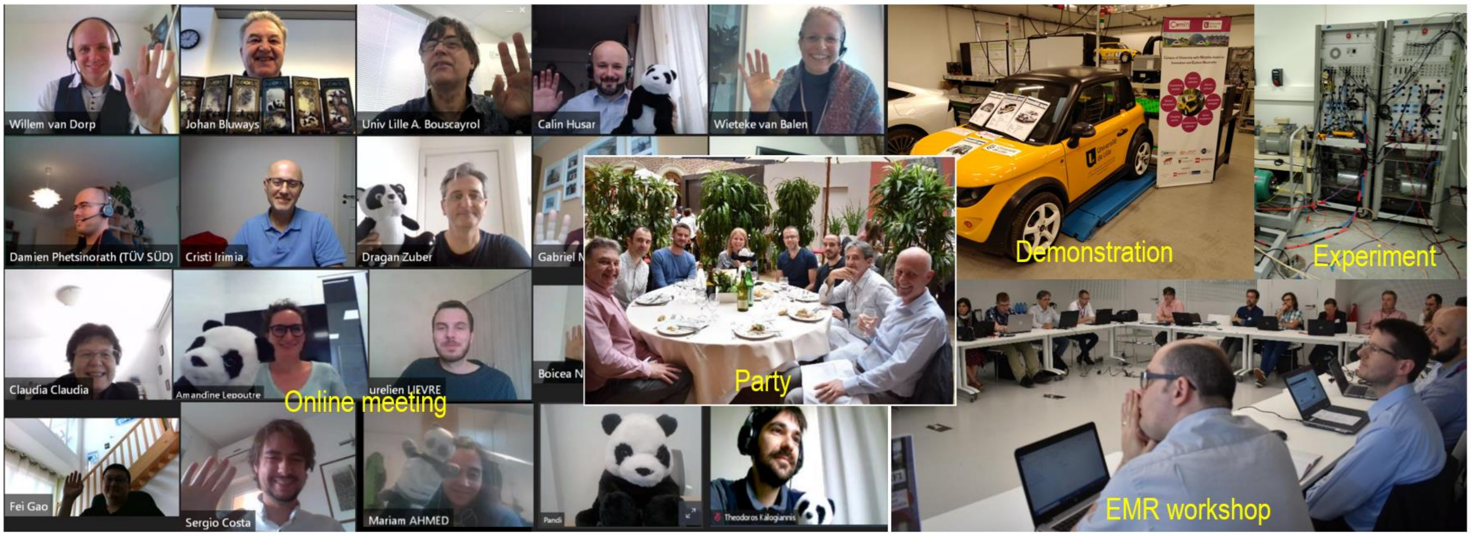

Figure 9. Various activities and events organized under the support of PANDA project (Source: https://project-panda.edu, used with permission).

for seamless integration of a complete vehicle model.

PANDA also has its own strategies for generating the "global actions."

- PANDA invited external experts from other related projects in the field of electric vehicles: Mr. Aymeric Rousseau (Argonne National Laboratory), Prof. C. C. Chan (University of Honkong), and Mrs. Corina Schreiter (Deutsches Institut fur Normung). The advisory Board meetings were organized during the project, to assess the progress and receive guiding advice. The external experts also provided final feedback to validate the results of the project and the continuity of the transnational mobility and the consolidation of interaction with the audiences.
- Since 2006, PANDA partners organized and supported the international EMR summer school (odd years in Lille and even years abroad) [13]. The summer school provides the students the general concepts, allows them to practice modelling and control practice using Matlab/Simulink™ with EMR library. The EMR experts introduce to them various applications and advanced topics. The success of the PANDA final event (150 attendees in-presence, 200 attendees on-line) can also be explained by the involvement of PANDA in these summer schools: a great number of the summer school attendees have registered for the final event.
- Similarly to OWHEEL, most of PANDA supervisors have actively participating into the organization of many international conferences. For years, the results of PANDA project and the EMR approaches have been discussed and presented at the IEEE Vehicle Power and Propulsion Conference (VPPC). The IEEE VTS Motor Vehicle Challenge has been organized in cooperation with VPPC since 2017. The Motor Vehicle Challenge is a special chance for the students to practice EMR and others to solve energy related issues for electric vehicles [14].

In summary, PANDA is a collaborative project which contributes to the development of automotive electronics as well as carbon neutral. The smiles in many faces in Fig. 9 clearly prove the project conclusion "A great success is always a teamwork" [11].

Example 4: "Shakai-renkei"

In Japanese, the words "shakai-renkei" (or 社会・連携 in Japanese character) mean social collaboration. Through shakai-renkei using the model in Fig. 4, many Japanese universities have established new educational programs or new laboratories to provide more chances for students and promote the cutting-edge research. An example is the Department of Advanced Energy (the University of Tokyo), which is constructed by both core-laboratories and social collaborative laboratories [10]. This department is where OWHEEL's seconded students conducted advanced motion control of electric vehicles.

Here is a successful example of "shakai-renkei" in Japan. This is the GREMO (Green Mobility Collaborative Research Center), which was established at Nagoya University in 2011. The distinctive features of GREMO are summarized as follows [15]:

- Organization structure: The researchers are gathered within three research areas: advanced vehicles, mobility services, and social impacts. GREMO tackles not only technology and services, but also issues related to legal systems and social acceptance.

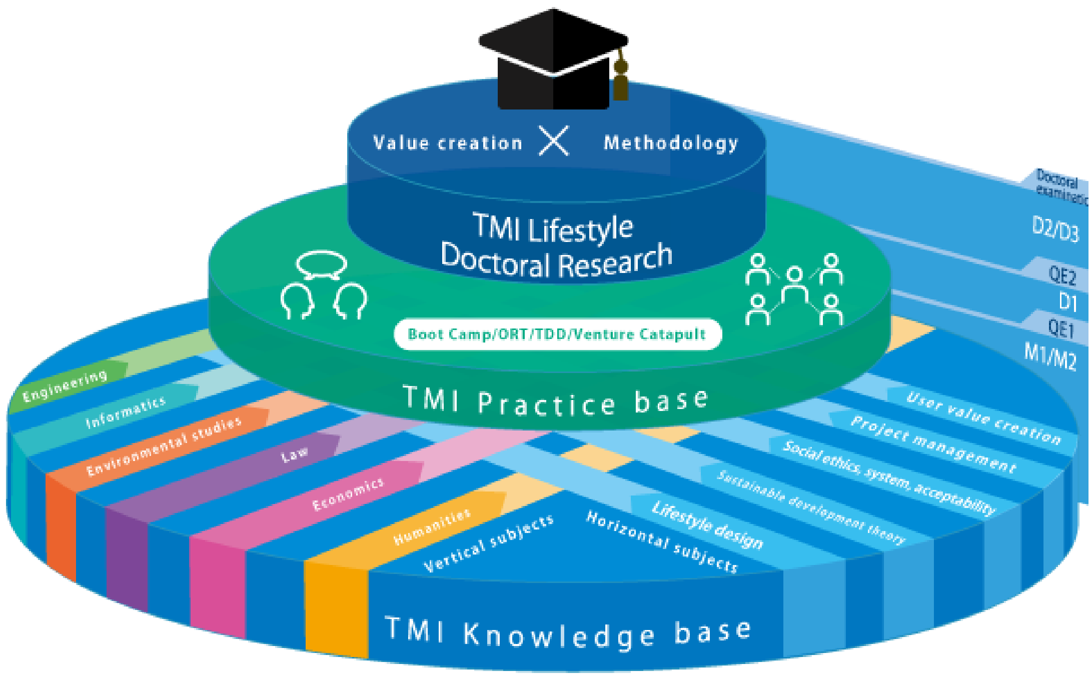

Figure 10. GREMO's three-layer PhD program curriculum (Source: www.gremo.mirai.nagoya-u.ac.jp, used with permission).

- Government support: Through national funded programs, such as JST-OPERA (Program on Open Innovation Platform with Enterprises, Research Institute and Academia) and JST-Mirai, researchers and engineers from different fields interact and engage in interdisciplinary research.
- Education philosophy: GREMO has been focusing on developing cross-disciplinary education programs to develop human resources who will play a prominent role in the next generation mobility research. Since 2017, GREMO has been offering Advanced Mobility Course to graduate students. In this course, leading industry and academia faculty members will provide lectures on various aspects of mobility. Especially, GREMO has numerous visiting professors from the industrial circles and foreign countries. In addition, GREMO maintains a balance between theoretical courses and practical training.

GREMO offers the students a 5-year-PhD program on Transdisciplinary Mobility Innovation (TMI). TMI has a three-layer curriculum, as shown in Fig. 10. The TMI Practice Base consists of:

- Boot Camps
- Onsite Research Training (ORT)
- Testbed Design and Development (TDD)
- Venture Catapult.

Boot Camps help building transdisciplinary collaborations in a team through overnight camps. In ORTs, the students conduct onsite research at different locations outside the university. TDDs provide students opportunities to design and develop a testbed as a basis for demonstration experiments by the collaboration with corporate mentors. The students can develop the autonomous mobile robot, EV sharing system, and urban sensing system. The Venture Catapult allows students to work together to plan and establish a venture company.

Together, Driving into the Future

In summary, we are at the dawn of a transformative era in the history of human transportation. The vehicle is no longer an individual possession. It would be a dynamic and intelligent companion shared by all society, in order to navigate safely, environmentally friendly, and economically. To advance automotive electronics and catch up the increasing requirements of the new era, collaboration has been recognized as the essential key. Many collaborative programs have been established all over the world, with different strategies and philosophies. By analyzing several successful examples, it can be believed that such model shares the same essence. That is, transdisciplinary education and research can only be realized by the warm hearts that connecting people from different fields, different organizations, different countries.

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