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Educating Global Engineers for Sustainable Energy: Integrating Systems Thinking, Mobility and Applied Learning

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Abstract

The integration of e-mobility into the energy mix plays a crucial role in reducing CO₂ emissions, as transportation remains one of the largest contributors to global greenhouse gas output. By addressing urban mobility challenges and optimizing electric vehicle systems, this teaching concept links technical competence with the broader goal of sustainable energy transition. At both universities, HAW Hamburg and Ecole Supérieure Polytechnique in Dakar, an electric vehicle serves as a learning platform in engineering science. These vehicles enable students to conduct electrotechnical investigations and perform simulations of energy consumption and usage patterns in urban traffic. The e-mobility topic arose in the course of a three-year cooperation between HAW Hamburg and ESP Dakar entitled 'Cooperation to Focus on Renewable Energy Education'. The approach aims to develop students' systemic understanding of energy flows and conversion processes. Learning activities are aligned with higher cognitive levels according to Bloom's taxonomy, supported by Biggs' constructive alignment of objectives, methods, and assessments. Students work interdependently on physical subsystems and a digital twin to analyse energy consumption and optimization strategies. Assessment combines documentation, presentations, and reflection to address cognitive, affective, and psychomotor domain. The concept has recently been implemented at HAW Hamburg under supervision of a lecturer from the Ecole Supérieure Polytechnique in Dakar, Senegal. The comparison reveals challenges in transferring learned skills to different infrastructural and cultural contexts. The research question is: How can engineering students be educated to develop a systemic understanding of energy processes and acquire the ability to independently optimize technical solutions for sustainable mobility?

Keywords: renewable energy education; e-mobility; project-based learning; constructive alignment; competency development.

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1 Introduction

The purpose of this paper is to present and critically evaluate a project-based teaching concept that uses an electric vehicle as a hands-on learning platform to foster competencies in renewable energy education. It aims to explore how engineering students can develop a systemic understanding of energy processes and control strategies and acquire the ability to independently optimize technical solutions for sustainable urban mobility. The e-mobility topic arose in the course of a three-year cooperation between HAW Hamburg and ESP Dakar entitled 'Cooperation to Focus on Renewable Energy Education'. The paper examines the implementation of this concept at HAW Hamburg under the collaboration of a professor from Ecole Supérieure Polytechnique in Dakar. As an outlook challenges and opportunities of transferring such learning approaches to the Senegalese University are discussed.

At both universities, HAW Hamburg and Ecole Supérieure Polytechnique in Dakar, an electric vehicle serves as a learning platform in engineering science. The course is held in the third of engineering studies. It addresses higher taxonomy levels of learning in a complex systems context. Training these taxonomy levels is essential in order for students to understand not only how technology works, but also its effects and the possibilities for influencing it. The electric vehicle is empirically examined and modelled, and then virtually tested in a traffic context. This allows predictions to be made about energy consumption in urban traffic and potential for optimisation to be identified.

2 Theoretical framework

The teaching concept builds on Bloom's taxonomy, which distinguishes three domains of learning: cognitive, affective, and psychomotor. While traditional engineering education focuses on cognitive knowledge, this module integrates hands-on activities and teamwork to address all three domains. To ensure coherence between learning objectives, teaching methods, and assessment formats, the concept applies Biggs' constructive alignment. Students progress through higher cognitive levels such as application, analysis, and evaluation, supported by real-world tasks and interdependent collaboration between the teams and their (sub-) systems.

2.1 Bloom's Taxonomy model

Bloom's taxonomy model has undergone numerous changes since 1956 (Anderson, 2001). The basic idea will be explained here using three different taxonomy levels based on the technical example of the e mobile.

- Descriptive Level: Students understand technical components such as electrical drive, controller, battery, transport profiles and energy consumption of the vehicle, ...

- Analytical Level (Analysis) Students analyse real measured data of the e-car, evaluate data of the Lithium battery, develop a GPS-module to track the speed of the car, ...
- Reflective Level (Evaluation and Perspective-Taking): Students validate and verify the developed systems and measured data to predict the car's behaviour...

2.2 Constructive alignment

The constructive alignment approach ensures that learning objectives, teaching methods and assessment formats are coherently aligned. Basic engineering skills of *Knowledge* and *Comprehension* are mainly taught during the first and second year. After developing these first two taxonomies (Bloom), this third-year module requires higher taxonomy levels of *Application, Analysis, Creation and Evaluation*. Higher taxonomic levels in the cognitive and non-cognitive domains require different examination formats (than just written exams) in order to do justice to the constructive alignment. The progressive development of competence levels throughout the Mechatronics program has already been described by the author in an earlier contribution (Usbeck, 2015).

2.3 Assessment

The examination format combines technical documentation, interim presentations, and regular feedback rounds to ensure continuous reflection and progress monitoring. To address a broad range of competencies, students work in teams of three to five persons and are assigned specific subsystems: electrical components, mechanical powertrain, battery, simulation, controller, and measurement technology.

Fig. 1 – Sample agreement between student team and teaching staff

<p>Group: Battery</p> <p>Team members: Schulz, Martene; Shahami, Ahmed; Zurkow, Maric</p> <p>Project: RiksHAW25</p> <p>Goals and tasks:</p> <ul style="list-style-type: none">• Conversion to Li-ion batteries• Understanding the functionality and wiring of Li-ion batteries• Inventory: Data on batteries, motor, controller• Mechanical integration: Mounting and fastening• Creation of new electrical wiring <p>...</p> <p>Evaluation criteria:</p> <ul style="list-style-type: none">• Customer requirements met• BMS, fuses and protective measures are correctly implemented• Electrical and mechanical components are neatly and stably installed• Circuit diagram and conversion process are clearly and correctly documented• Time management and adherence to deadlines <p>Grade agreement:</p> <ul style="list-style-type: none">• We would like a group grade <p>Signatures of team members</p>

Source: Agreement of 'Mechatronic Design' course in summer 2025

Each group is responsible for developing and optimizing its subsystem so that, by the end of the semester, the electric vehicle operates in an improved state. This includes test drives to check the functionality of the electric drive and the battery. During the test drives, the quality of the measurement data collected must also be ensured. The simulation model is compared with the measurement data in order to create an optimised simulation model of the electric vehicle.

In order to address individual students equally, the overall goal is discussed together at the beginning of the semester, and the sub-goals are roughly defined. The student teams then draw up a contract listing the tasks and assessment criteria for achieving the individual goals. The lecturer and students agree at the beginning on what can be achieved during the semester (see Fig. 1).

3 E-mobility as an objective

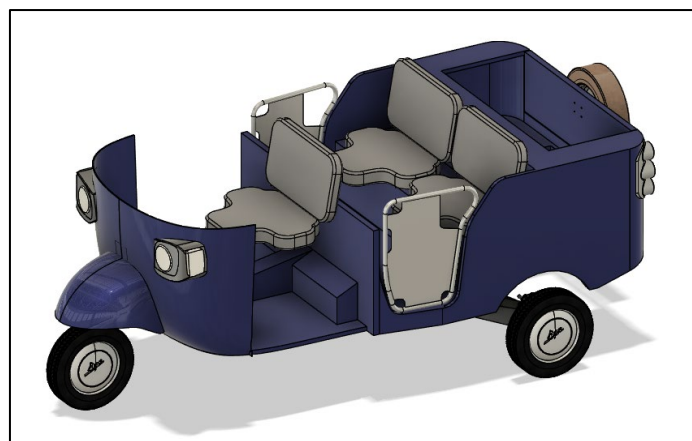
The e-mobility platform enables students to apply engineering methods learned in former semesters and collaborate across domains. By running the car under different operation conditions, time, load and control parameter-dependent system behaviour can be analysed. Modelling and simulation tools like MATLAB/Simulink and CAD support digital prototyping.

3.1 Implementation e-mobility as a hands-on learning-platform

An APE Calessino, a three-wheeled vehicle that has been converted from a combustion engine to electric drive in the university's workshop. It now serves as a teaching platform with open access to controller, electric, gear and battery. The small size and low power (5.5 kW, 48 V) allow students to work autonomously and safely on individual subsystems.

An image of this APE Calessino can be seen in Fig. 2. as a result of the 'Design and Development' group (groups will be described below). In addition to remodelling the original APE in 3D, also a design adjustment to two-wheel hub motors in CAD.

Fig. 2 – CAD model of the redesigned APE Calessino

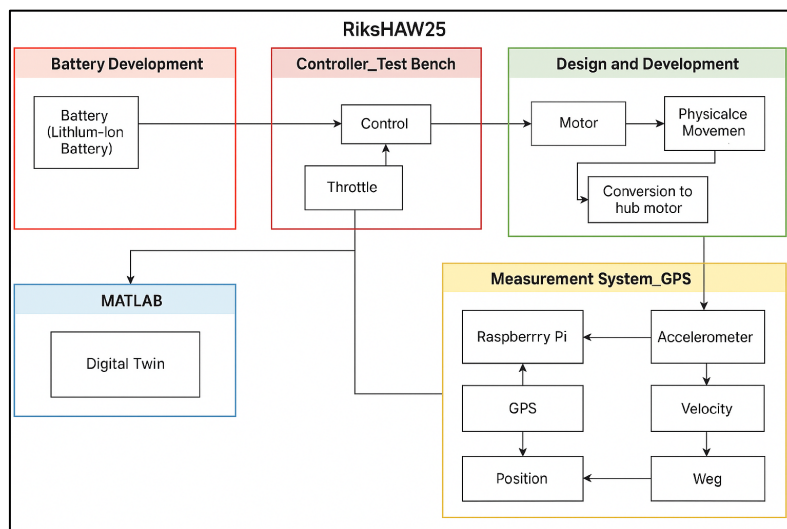


Source: Results of Group "Design and Development" (2025)

The open access makes it possible to make changes on different components in a practical manner. Different sub-systems such as the electrical motor, the mechanical power train, the controller, which runs the electrical motor, the battery and its charging characteristics, are analysed and developed further. An additional GPS system is developed to supplement the controller's measurement data with geographical data (e.g. elevation profiles).

Complementary to the groups working on physical systems with empirical data, there are other groups dealing with the virtual prototyping as well as the measuring systems. The main application of modelling and simulation tools (in particular MATLAB/Simulink and CAD) are used for a digital simulation of the power train and the CAD-model of the vehicle. Both tools are main part of the nowadays digital engineering. As shown in Figure 3, the five different student groups work interdependently (with interfaces) on sub-systems. The sixth student group will work in the role of project management.

Fig. 3 – System setup and interdependencies of the working groups



Source: Results of Group 'Project Management' (2025)

3.2 Student profile

The module targets third-year engineering students with prior knowledge in electrical, mechanical, and control engineering. It emphasizes higher cognitive skills such as analysis, synthesis, and evaluation, assessed through project outcomes and documentation. In addition to cognitive learning, teamwork and hands-on activities activate the affective and psychomotor domains. In table 1 the different tasks of the module are linked to the different domains of Bloom's taxonomy.

Table 1 – Three Dimensions of Learning

Domain	Content
Cognitive Domain	Understanding system architectures, modelling techniques, and development processes; applying engineering methods and evaluating system behaviour
Psychomotor Domain	Implementing, operating, measuring physical subsystems; using tools and lab equipment to realize functional prototypes
Affective Domain	Collaborating in teams, taking responsibility for tasks, reflecting on group outcomes, and committing to quality and ethical standards

Source: Author's own data, module 'Mechatronic Design', Summer 2025 according to Bloom's taxonomy

3.3 Design process

The students work on their subsystems in individual working groups. As in industry, they are therefore required to be aware of the interfaces with the other groups and to coordinate with each other. These coordination processes are described in VDI 2206 and can be applied to the student groups: "[A] suitable exchange of information must take place between product design and production system design. This is to be coordinated in three dimensions: time, content and intensity of the cooperation." (VDI 2206).

4 Recent tasks and outputs

4.1 Group activities outputs

All groups contribute to the optimization of the e-vehicle platform. The groups achieved the outputs listed in Table 2 within one semester in terms of time and content. In doing so, they are more or less dependent on the cooperation and specifications of the other groups.

As an example: The location for battery installation must be agreed with the 'Design group', the battery can only be operated with the correct controller settings, and the MATLAB simulation relies on measurements from the controller and GPS data acquisition. Table 2 is a summary of the student reports. In addition to the 'main task', which is defined in the agreement at the beginning of the semester, the 'output', describes the actual results at the end of the semester. Essential for the higher taxonomy level in teaching is the column of the 'Challenges', which represents the students' reflections on the extent to which the assumptions made at the beginning of the semester were correct and what difficulties arose.

Table 2 – Outputs of the individual groups

Group	Main Task	Key Outcomes	Challenges
Battery Development	Replace old lead-acid batteries with modern Li-Ion batteries	Improved system reliability and range; successful test	Existing batteries failed due to parallel connection.
Controller / Test Bench	Optimize motor controller parameters	Successfully limited motor current; improved driving behaviour; validated MATLAB scripts.	Initial lack of understanding of controller parameters; current limits required experimentation.
Design and Development	Design and model a new drive system using hub motors; create CAD models and assembly instructions.	Developed a complete concept with CAD models and cost analysis; prepared for future implementation.	Risk of incorrect measurements and incomplete documentation; emphasized need for better planning.
MATLAB Simulation	Create a digital twin of the electric drive system using MATLAB/Simulink; validate with real driving data.	Built a functional simulation model; validated with real data; used for energy consumption estimation.	Simplified model lacked battery and thermal effects; future improvements suggested for realism.
GPS	Develop a GPS-based data logger for vehicle tracking and acceleration measurement.	Built and installed a modular GPS system with Raspberry Pi; successfully tested during public event.	I2C multiplexer failed; limited sensor integration; required redesign of system architecture.
Project Management	Coordinate all project teams; documentation, and communication.	Structured project; ensured smooth collaboration; supported all teams effectively.	Verbal communication led to misunderstandings; emphasized need for written documentation.

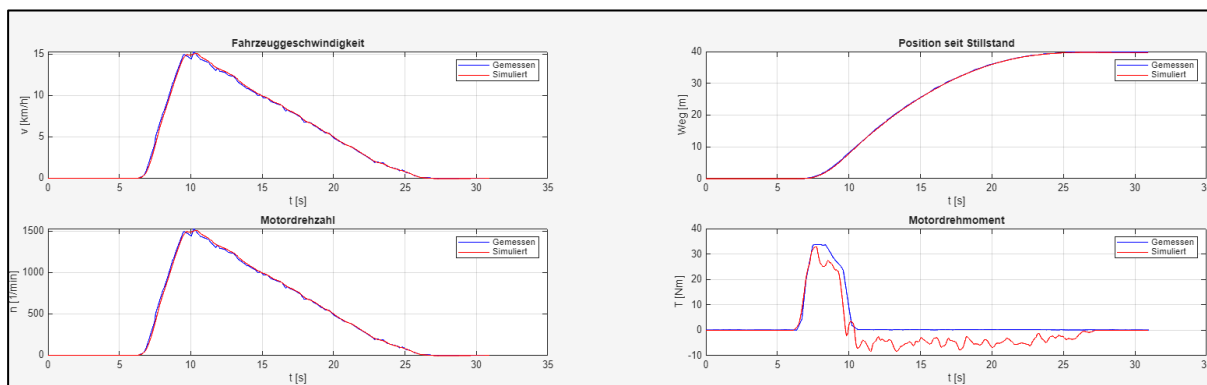
Source: Author's own data, module Mechatronic Design, Summer 2025

4.2 Interdisciplinary result of the optimized Rikscha APE Calessino

The overall result of the work is an optimized controller, which ensures that the battery current is limited to 100 A, a new working lithium battery, evaluable GPS and Controller Data and CAD model and a MATLAB digital twin. The digital twin maps the APE with its control parameters, allowing specified driving profiles to be used to forecast energy requirements and battery discharge. In figure 4 the measured data of one tracked journey in blue colour is

compared to the simulation of the digital model in red colour (speed (v), position (s), rotations of the motor (n) and motor torque (T)). In the long term, the data can be used to perform simulations in urban traffic and to design a charging infrastructure that is suitable for the electric vehicle fleet.

Fig. 4 – MATLAB simulation and real measurement – comparison



Source: Results of Group “MATLAB” and “Controller/Test Bench” (2025)

5 Evaluation and student perspectives

5.1 Evaluation from teaching perspective

An electromechanical system was systematically examined, modelled and improved by the individual groups over the course of a semester. The groups understood how to apply their knowledge of electrical, mechanical, electronic and programming technology. Through the complete analysis and description of an electric vehicle, the essential technical aspects of efficient energy conversion and storage were addressed at a high level.

5.2 Feedback from students

Feedback from students was not systematically collected but can be summarised as follows based on the comments in their documentation: The students demonstrated high motivation and active participation throughout. In addition to deepening their technical skills, teamwork and communication skills were strengthened, particularly with regard to coordination between interdisciplinary groups. The project proved to be an effective learning environment for technical creativity, systemic thinking and practice-oriented collaboration, preparing students for future organisational and technical challenges.

5.3 Feedback from Senegalese lecturer

German students are much more independent in their activities. While in Senegal, the lecturer is called in at every step and has to approve the work, students in Germany are given

tasks and are assessed on the results. The agreement that students must sign at the beginning of the semester is to be tried out as an activating feature at ESP Dakar in the future.

5.4 Challenges and learning impulses

Students initially struggled with open-ended tasks and interdisciplinary coordination, but these challenges fostered personal responsibility and collaborative problem-solving. Stress and tensions were part of the process but resolved through shared achievement. A key challenge in project-based learning lies in ensuring a clear understanding of the problem and associated tasks from the outset, that student teams are intrinsically motivated, and the fixed deadline tied to the project goal. Supporting students through these challenges and fostering resilience are essential to the development of competencies that extend beyond technical expertise.

6 Conclusion and outlook

The teaching concept presented for the APE Calessino shows how sustainable mobility can be taught in engineering studies not only in theory but also made practically tangible. The combination of real vehicle data, simulation-based analysis and reflective engagement with global mobility issues creates a multi-layered learning space that combines technical competence with social responsibility. The positive feedback and high level of self-motivation among students confirm the educational value of the concept.

There are plans to further develop the teaching concept and to work on the digital twin both Ecole Supérieure Polytechnique Dakar and HAW Hamburg. This offers potential for joint projects and intercultural exchange.

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This PDF contains the chapter "Educating Global Engineers for Sustainable Energy: Integrating Systems Thinking, Mobility and Applied Learning" (<https://doi.org/10.48544/d4392a7b-6a60-4a6c-9453-2dafdb0e20ad>) from the Proceedings of the Second International Conference on Sustainable Energy Education (SEED 2026) (Academic Papers - Proceedings of the Second International Conference on Sustainable Energy Education (SEED 2026). Utrecht, the Netherlands, 24-25 March 2026), together with the original front matter and imprint. All other chapters, the table of contents, and additional proceedings material have been removed. The content of the included chapter has not been modified.

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