Virtuous, multi-level integration of research and education within the project "European Digital Dynamic Mapping" (EDDY)

Excellent applied research as an enabler for excellent education in the context of Project-Based Learning in Higher Education Institutions

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Abstract: Project- and Problem-Based Learning has been subject to research and implementation in engineering and computer science curricula for about the last 20 years. However, the projects and problems focused on in education have hardly been questioned for their relevance and effect. Considering current global and financial challenges, the authors propose to revise project- and problem-based approaches in education in the context of relevance and excellence in applied research. Besides coping with current cost-cutting, existing control mechanisms could ensure both relevance and excellence. Example projects based on more than 10 years of hands-on experience in Project-Based Learning in the context of externally funded research, for various classroom situations are included.

Keywords: Project Based Learning (PBL), Research and Education, Funded Projects, Mobility, Autonomous Vehicles, Data Analysis

1 Introduction

Over the last decades, education in engineering and computer science shifted from strict fact- and method-based, chalk-and-talk [MT03] learning towards problem- and project-based education. Main drivers for this paradigm shift were substantial changes in the engineering environment with increased levels of volatility, uncertainty, complexity, and ambiguity (VUCA) [Ci23]. New skills were required, like agile development methods, deriving information based on the analysis of huge data pools, Machine Learning (ML), and many more. In parallel, the future employers of engineering graduates identified a lack of required skills for the modern workplace, including communication and cooperation capabilities in an internationally shared work environment. At the same time,

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universities faced a lack of students in the fields of Science, Technology, Engineering and Mathematics (STEM). Specifically, many Universities of Applied Sciences, subject to constant cost-cutting, did not keep up with the innovation pressure and limited their education program development to managing the status quo at controlled or minimized effort. Processes, like the update of curricula, were slow and did not reflect consequences of VUCA and the high speed of development of new requirements and competencies. As a measure, Project- and Problem-Based Learning (PBL) was introduced to foster the development of the new skillset. This led to the introduction of many toy-based projects without real-life relevance. However, without a funding source beyond the universities own budget, cost pressure led to a reduction of project-based education. Teaching lacking skills was partially left to industry to educate in the final semesters during internships or within dual degrees. However, this approach led to raising the question of the future role of Universities of Applied Sciences, if they were neither providing the relevant education, which is outsourced to industry, nor generating research results advancing society, which was left to (technical) universities with significant scientific ambitions and focus.

2 Related Work

PBL in engineering has been subject to research since about the turn of the century and has been introduced in many engineering and computer science curricula over the last decade. Recent publications include the idea of a Curriculum 4.0 to address COVID and VUCA requirements [Ci23]. The authors describe case studies from two different European universities. Other relevant publications include [MT03, PL11, MSH22]. The authors consistently focus on the learning outcomes of the students, but face difficulties in measuring results on a standardized scale. The authors of [BK22] analyze students' motivation and find that "Students live and learn in the real world". Thus, they need to know "that their work matters", and it is not sufficient to setup a "toy based" PBL. Consequently, project outcomes must be connected to real-life, beyond the state-of-the-art problems.

3 Questions of Research, Methods, and Objectives

Based on a mixed qualitative and quantitative assessment, the authors review their experience in project-based education for proven real-live projects, which withstand scientific scrutiny. Furthermore, a strategy for implementation within courses at Universities of Applied Sciences should allow readers to make best use of the author's experiences. The following core questions address the perspectives of "prerequisites" and "implementation":

- How to create PBL experiences based on relevant, real-live problems? What are the prerequisites? How to prove relevance?

- How to bridge the gap of missing financing?
- What are strategies to be considered for successful implementation in the context and limitations of research and teaching at a University of Applied Sciences?

4 Virtuously connecting excellent research and excellent teaching within the project EDDY

The project "European Digital Dynamic Mapping" (EDDY), started 2021, was funded by the Federal Ministry for Digital and Transport within the innovation initiative mFUND [FM21, FM23] for a total duration of 36 months. The main goal of the project is the development and implementation of Local Dynamic Maps (LDMs) [ET11, Ei19] to enable autonomous vehicles, reduce traffic emissions, and protect vulnerable road users. Specifically, the roles and responsibilities of cities and municipalities as the owner of public roads are to be revisited. The total project volume is almost € 3.6 million with work packages shared among seven project partners including the Free and Hanseatic City of Hamburg, the German Aerospace Center (DLR), the Hamburg University of Applied Sciences and four industry partners.

The Urban Mobility Lab at the Hamburg University of Applied Sciences contributes in multiple ways to reach the project goals: Main task is the prototypical implementation of an LDM-based visual localization system, which provides means for landmark based localization in areas with systematically wrong or insufficient GNSS signals. This complex subproject requires a combination of multiple skills in engineering and computer science disciplines, like visual, camera-based object classification in real time, multi-dimensional data-analysis, and complex, Kalman-based filtering. On top of that, strong application knowledge in the field of highly automated vehicles is a prerequisite to successfully tackle the project. It is subject to significant research over the last decade, as indicated by multiple publications in the field [Zh11, Sp15, Da22].

On top of the main task within EDDY, a significant number of additional ideas were developed during the project. Since localization based on point-objects was the base, additional tasks were taken over to classify and collect data for objects relevant for the project partners, which were not necessarily suitable for localization. Thus, as an example, the automated detection and localization of construction site beacons was identified as a value add for the city.

In total, all projects initiated since the beginning of EDDY can be classified into four groups, as summarized in Table 1.

Project Level	Name	Semester (typ.)	Duration (months)	Scientific Relevance
1	Standard Curriculum	4-6	3	0
2	Single-student and Team Projects	4-5	3	0
3	Bachelor Thesis	7	3	1
4	Master Thesis	10	6	2
5	PhD	16	36	3

Tab. 1: Overview of project classifications; "scientific relevance": Potential for peer reviewed publications 0: none to 3: 100 % (must)

4.1 Level 1 – Integration into the Standard Curriculum

Since 2013, the author regularly teaches "Sensors in Mechatronics" in a one semester course in the 6th semester based on a classroom-focused, project-based approach with changing assignments as indicated in Table 2.

Semester	Project description	No. of students / No. of teams	Real-live relevance	Key-findings in formal students' evaluations and direct feedback
SS13	Automated Parking	6/6	Toy-Robot	+ First time release from frontal-lecture-jail
WS13/14	Collision Avoidance	35/11	Toy-Robot	- Too little technical input from the lecturer + No frontal lectures, students' initiative counts
WS14/15	HAW Luftschiff [HA13]	34/11	Toy-Robot	
WS15/16	HAW Seaglider	31/10	Toy-Robot	+ Organization +/- Demanding project - Too few direct technical inputs from the lecturer
WS16/17	Spherobot [HA16]	21/7	Toy-Robot	

Semester	Project description	No. of students / No. of teams	Real-live relevance	Key-findings in formal students' evaluations and direct feedback
WS17/18	Magnet finding submarine [HA17]	18/6	Toy-Robot	
WS 18/19	Indoor Mapping [HA18]	15/5	Toy-Robot	
WS 20/21	Automated Platooning	22/8	Toy-Robot	+ Extremely good learning atmosphere + Ratio of technical inputs and project work
WS 21/22	Various, related to funded projects	25/7	Real, Projects contribute to EDDY	
WS 22/23	The safe-bike-box (EDDY)	23/7	Real, Projects contribute to EDDY	+ Student's feedback: "First time real-life mechatronics projects"

Tab. 2: Overview of level 1 project-based education.

Starting in the winter semester 21/22 the projects were directly associated with the project EDDY. Specifically, in the following winter semester, all teams were assigned the task to develop their "safe-bike-box" (Figure 1), a sensor and communication system to be integrated into an electric bike to measure the street quality and automatically detect evasive maneuvers by the cyclist. The data and events were to be sent to the local dynamic map server of the EDDY project and visualized with a geographic reference (Figures 2 and 3). Industry partners of the project supported by providing server access and by personally introducing visualization frameworks to the students. The direct input from industry partners was a significant motivator for the students and underlined the relevance of the assignment. The course was tightly organized based on the semester schedule with weekly mixed lecture and lab appointments. Technical inputs, for example on data structures or server communication, were included in the lecture segment. The progress of each team was closely monitored, with biweekly, team-specific feedback including technical aspects and the team progress. All teams reached the assigned goal with various creative add-ons and demonstrated their individual solution in a drive test at the end of the semester.

Students' evaluations consistently indicate a "very good" overall impression of the lecture with chances for improvement concerning the students' overall time effort and the balance of project work with technical content directly delivered by the lecturer.

Fig. 1: Safe-Bike-Box mechanical setup [Ba23]

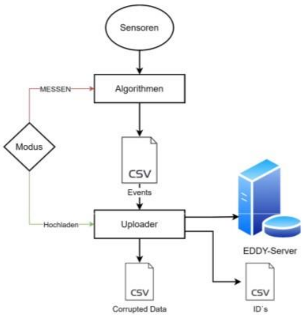

Fig. 2: Safe-Bike-Box data flow [Ba23]

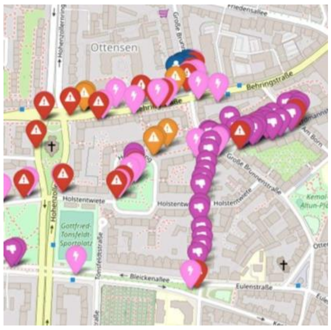

Fig. 3: Safe-Bike-Box measurement results [Ba23]

The main characteristics of the level 1 projects are:

- Tight, regular schedule for all teams (like lecture and lab).
- Mix of classroom, lab, and free working on the assigned project.
- Regular in-plenum technical inputs, joint progress reviews (technical, process).

The main learnings and observations are:

- A common task for all teams supports the effort and adds aspects of competition and cooperation.
- A strong start with a clear goal for the semester is required.
- Variable roles of the educator: Starting as the "customer setting the goals" to "providing technical inputs" to "observing each teams progress and providing support as a coach" and finally as the "examiner providing a grade for the result".

4.2 Level 2 – Single-Student and Team-Projects

One of the main measures to reflect PBL in the curriculum of Mechatronics was the integration of a bachelor project in the 4th semester. The project is scheduled for a duration of three months and runs in conjunction with an introduction to project management. Within the first months of the project EDDY, the need for inline anonymization during the test-drives for visual localization became evident and a jetson-nano-based system was developed by a team of three students (Figure 4). The system was integrated into the test-vehicle measurement system. Furthermore, the use of local dynamic maps for the coordination of construction sites was discovered as a side-use, not planned in the original project (Figure 5). Another team of three students successfully pursued this task and integrated a detector for construction site beacons into the test vehicle setup.

Fig. 4: Inline anonymizer [SVB23]

Fig. 5: Detector for construction-site beacons [GWH23]

The main characteristics of the level 2 projects are:

- Start with a defined, written goal for the project and work-products including their quality.
- Open lab, access to the Urban Mobility Lab at the university.
- Biweekly, on-demand reviews on progress and results.

The main learnings and observations are:

- A detailed, written project charter is a must to avoid the project running off-track.
- These projects typically run into phases of low priority, which lead to delays.
- Due to the variable timing and availability of the students, the best practice was to connect to the project EDDY content-wise but to keep the timing disconnected.
- Good documentation is a priority to be able to use results in follow-up projects.

4.3 Level 3 – Bachelor Thesis Level

The duration of a bachelor thesis in Mechatronics at the Hamburg University of Applied Sciences is three months. During this time, the student is supposed to be fully focused on the bachelor thesis. Figures 6 and 7 shows a result, conducted in conjunction with EDDY. A measurement system for the classification of vertical acceleration and jerk was developed and connected to the EDDY-server to measure and document insufficient street quality.

Fig. 6: System setup [Pl22]

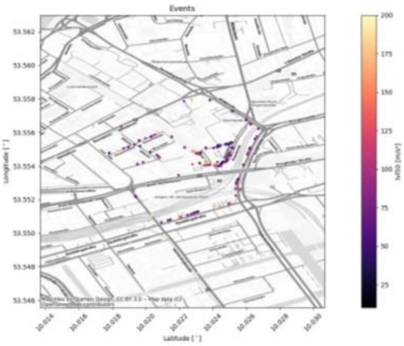

Fig. 7: Street quality events [Pl22]

The main characteristics of the level 3 projects are:

- Start with a defined, written goal for the project and work-products including their quality.
- Full integration into the lab and research team.
- Biweekly, on-demand reviews on progress and results.

The main learnings and observations are:

- A detailed, written project charter is a must to avoid the project running off-track.
- Full dedication of the student is a must.
- External funding allows financing of tasks with direct project relevance (student tutor, part-time research associate, payment within industry standards) and required material.
- Partially, close coupling with external projects is possible.
- Good documentation is a priority to be able to use results in follow-up projects.
- Typically, only about 5 % of the bachelor thesis are of sufficient scientific quality to create peer-reviewed publications.

4.4 Level 4 – Master Thesis Level

Due to the longer duration of a master thesis of six months, and the advanced technical and methodological competencies of the students, a significant increase in complexity is expected. The master candidate was working fully integrated into the research project EDDY and paid within industry standards for students in their master thesis. A localization system for the test vehicle (Figure 8) to complement other localization techniques in locations where they do not work (Figure 9), was developed. The system used landmark-based localization (Figures 10 and 11).

Fig. 8: Test vehicle of the Urban Mobility Lab [WE23]

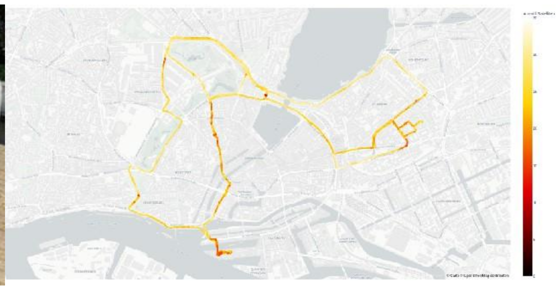

Fig. 9: GNSS-performance along the test track for automated and connected driving (TAVF) [We23]

Fig. 10: Basic functionality for landmark-based localization [We23]

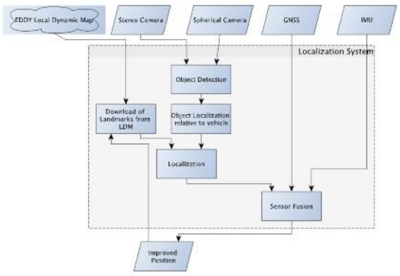

Fig. 11: System developed within a Master Thesis [We23]

The main characteristics of the level 4 projects are:

- Start with a defined, written goal for the project and work-products including their quality.
- Full integration into the lab, the research team, and the project EDDY.
- Regular, weekly review on progress and results.

The main learnings and observations are:

- A detailed, written project charter is a must. However, due to the length and complexity, adjustments may be required.
- Full dedication of the candidate.
- External funding allows financing of tasks with direct project relevance (student tutor, part-time research associate, payment within industry standards).

- Good documentation is a priority to be able to use results in follow-up projects.
- Currently, only about 10 % of the Master Thesis are of sufficient scientific quality to create peer-reviewed publications.

4.5 Level 5 –PhD-Thesis Level

Up to writing this publication, no PhD was completed within the project EDDY. However, the author successfully lead a candidate up to reaching a “Dr. phil.” within the funded project “X-eptance Impulse” [XE21].

The main characteristics of the level 5 projects are:

- Initial finding-phase to identify relevant questions of research.
- Full scale scientific discovery process, incl. dead ends.
- Full integration into the research team and project (full time research associate).

The main learnings and observations are:

- PhD-level long-term involvement is a must to reach a sufficient level of competencies and knowledge to reach international acceptance.
- Due to the lack of permanent mid-level scientist positions for research at Universities of Applied Sciences, external funding is a must.

5 Results and Discussion

Based on the analysis of level 1 to level 5 projects, the keys to successfully integrate research and education at Universities of Applied Sciences are:

- Consistent and continuous acquisition of external funding for several years.
- Paid research associates (Master or PhD level) focusing on the project for longer periods are required to reach a sufficient competence level to successfully compete and contribute to science.
- Shorter project types must be smartly structured and well controlled to contribute to funded projects.

6 Summary and Outlook

Virtuous integration of research and education is the key for Universities of Applied Sciences to stay relevant and competitive in the development of science and education.

Funding is a must and successful acquisition is a valid indicator to demonstrate relevance for industry, science, and society. By smartly integrating existing strengths, system-immanent deficiencies, like the lack of permanent midlevel positions for scientists, can be overcome.

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8 Author's Contributions

Rasmus Rettig: Conceptualization, Methodology, Writing, Funding Acquisition, Supervision. Maximilian Weltz: Investigation, Visualization, Writing, Review & Editing.

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