Project-based Learning in a Geomatics Bachelor Program: A Digital Heritage Preservation Project

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Abstract

Like in most bachelor engineering programs, the education of geomatics students typically begins with an extensive theoretical introduction covering fundamental subjects. The general objective of the bachelor program is to cultivate geomatics engineers with robust hands-on knowledge. Nevertheless, the progression to a stage where students can independently engage in exercises with minimal supervision is a long process. Although field work-based practices are dominant in this field, they often entail activities limited to testing, experimenting, and the application of basic theories. While this approach is efficient in imparting routine knowledge, it may lead to the fragmentation of acquired knowledge, thereby lacking a comprehensive understanding of the broader significance and context. Students often encounter more complex challenges when commencing work on their bachelor thesis, leading to a steep learning curve within a constrained timeframe. This late exposure to real-world tasks can be a limiting factor, hindering a smoother transition from education to professional work.

This paper provides a case study of project-based learning (PjBL) within a geomatics bachelor program. Specifically, it discusses a digital heritage preservation project where students documented an old Norwegian log house throughout the autumn semester of 2023. The outcomes of this learning approach are analyzed with the help of the key features of the PjBL methodology, focusing on students' learning outcomes and their assessment measures.

1. Introduction

1.1 From experimental learning to project-based learning in geomatics education

"Learning by doing" is a well-established practice in geomatics engineering education. Typically, each time students acquire proficiency in a new observational method and its theoretical background, the most critical phase of the learning process is the practical application. This involves initial repetitive practice of a specific observational type, progressing to more intricate tasks where the observation is applied in a typical context. Consider the example of learning the differential levelling method: once a student gains confidence in making accurate single observations, they progress to practicing double runs along several levelling lines. As a more contemporary illustration, after mastering the handling of Terrestrial Laser Scanners (TLS), students engage in tasks such as cloud-to-cloud registration of scanned point clouds. The complexity of the task correlates with the challenges students face, contributing to the development of their understanding and skills. Availability for questions during this process is crucial to prevent students from feeling overwhelmed by the complexity of the challenges.

Experimental learning as a pedagogical methodology is well-documented. In Figure 1, the application of Kolb's experimental learning cycle (Kolb, 1984) and (Healey and Jenkins, 2000) in the context of a complex observational technique provides a comprehensive overview of the learning process students undergo. Table 1 summarizes the application of Kolb's theory (Kolb, 1984) to the examples described above, offering descriptions of each step as provided by Healey and Jenkins (Healey and Jenkins, 2000), along with examples from geomatics education.

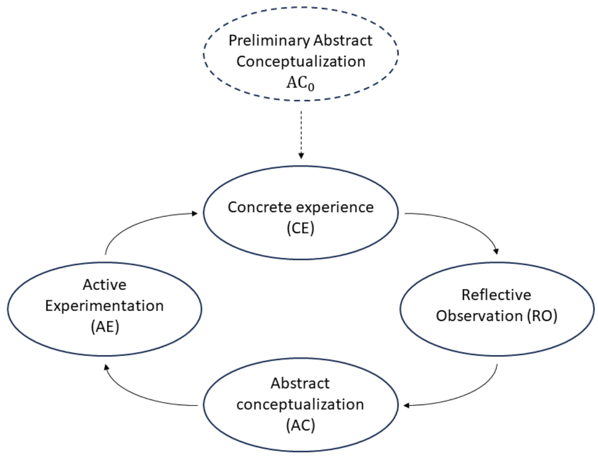

Figure 1. Updated experimental learning cycle - based on Kolb (1984) and Healey and Jenkins (2000)

Figure 1 depicts an updated version of the renowned experimental theory figure with an additional step aligning with the example mentioned earlier. In geomatics education, the theoretical introduction precedes every experimental session. This is pivotal, given that most observation methods taught at the bachelor's level adhere to well-established procedures, unlikely to be developed by students from scratch based solely on trial-and-error experiences. This preliminary theoretical introduction provides students with a "preliminary concept" or an opportunity for "preliminary abstract conceptualization" called AC0. The first experience (CE) is typically based on this preliminary concept.

Concrete experience (CE)	Where the learner is actively experiencing an activity.
	When the student tests a specific (observation) method the first time.
Reflective Observation (RO)	Where the learner is consciously reflecting back on that experience.
	When the student post-process the observation data and assess the results.
Abstract conceptualization (AC)	Where the learner is presented with or trying to conceptualize a theory or model of what is to be observed.
	When the student matches the experiences to the previously learned theory.
Active Experimentation (AE)	Where the learner is trying to plan how to test a model/theory or plan for a forthcoming experience.
	Based on the experiences and reflections, a more complex task is to be carried out (planning an action).

Table 1. Steps of experimental learning cycle as described by Healey and Jenkins (2000) with examples from geomatics.

A more complex form of experimental learning is project-based learning (PjBL). Project-based learning is an inquiry-based instructional method that involves learners in acquiring knowledge through meaningful projects, resulting in the development of real-world products as described in (Pengyue et al., 2020). Geomatics students, engaging in PjBL, confront real-life problems. While solving these problems, they draw not only on their previously acquired experiences, both theoretical and experimental, but also on their problem-solving skills when faced with unique, project-related challenges. Despite addressing real-world challenges, students still work in a controlled environment; a key advantage of this learning style is that it allows educators to integrate real-world challenges with academic rigor.

Overall, the positive impact of PjBL on STEM education has already been demonstrated: the development of participating students' knowledge and skills has increased, proven by Ralph (2016) and Pengyue et al., (2020). Additional results on the effectiveness of PjBL in geomatics education have been reported in numerous instances, such as in LiDAR (Maldonado et al., 2021) and remote sensing-related courses (Mesas-Carrascosa et al., 2019), and even in a multidisciplinary international collaboration (Zubinaite et al., 2023). Additionally, the long history of PjBL implementation has been documented for specific cases (Höhle, 2005).

1.2 The program and subject

This paper details a project-based learning session part of the bachelor's program in geomatics at the Norwegian University of Science and Technology in Gjøvik (NTNU in Gjøvik) during the autumn semester of 2023. This bachelor's program provides two specialization options: surveying and geoinformatics. The specific project discussed further down in this paper was organized within the Terrestrial Laser Scanning course, an elective subject popular among students from both specializations. In this course, students delve into the concept of laser scanning, the nature of scanned data, the latest scanning devices, and their applications. Throughout the semester, students gain practical knowledge, including fieldwork and data pre- and post-processing, integrated into the curriculum. The results of these fieldworks and processing experiments are submitted as assignment reports. This paper presents the lesson learnt from such a project.

1.3 The students

Six bachelor geomatics students participated in the project, each with different backgrounds. Five were third-year students, fifth semester, the last semester before starting their bachelor thesis, and one was a second-year student in the third study semester. Their practical experience level varied, some started the program directly from high school, while others had non-geomatics-related work experiences. Additionally, some students had already completed summer internships at geomatics firms. The nature of tasks involved in this project was novel for each student.

2. The project goals

The project aimed to digitally document the current state of an old log building located in the park of the Maihaugen Museum in Lillehammer, Norway, utilizing terrestrial laser scanning technology. Maihaugen Museum, established in 1887, stands as one of the oldest and largest open-air museums in Europe, boasting a collection of over 200 buildings from different historical eras (www.maihaugen.no).

It is widely acknowledged that the application of geomatics technologies for recording, visualizing, and potentially restoring and digitally reconstructing cultural heritage resources is an effective tool (Stylianidis, E. and Remondino, F., 2016). The resulting datasets can be utilized for disseminating knowledge and information for educational, research, risk assessment, planning, and design purposes related to cultural heritage conservation, as summarized by Storeide et al. (2023).

Figure 2. The tannery building in Maihaugen Museum (photo: Maihaugen, www.digitalmuseum.no)

The selected building, shown in Figure 2 was originally a tannery from the mid-19th century. When it was relocated to the museum's park in 1907, its proximity to a creek was maintained for authenticity, as water was vital for a tannery. However, floods from the creek periodically had impacted the building's structure and foundations, leading the museum management to plan its delicate relocation. Therefore, precise documentation of

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the building becomes crucial for this delicate and meticulous process.

Before settling on this particular building, others with different sizes, appearances, and historical backgrounds were offered for scanning. The students chose the building prioritized by the museum, despite the higher difficulty of scanning. When inquired about their choice, the students emphasized the project's usefulness. Recognizing the museum's emphasis on the importance of documentation, by selecting this building they believed their contribution to the community would be the most significant. This demonstrated their understanding of the significance of cultural heritage conservation, i.e., preserving objects, architecture, or historic places in their current state to maintain authenticity, materials, and values.

The technology provided for digital documentation was stationary terrestrial laser scanning using a Leica P40, available in our geomatics bachelor program. The scanner delivers accurate 3D data with minimal noise at a very high scanning rate (1 million points per second), although its stationary nature without an IMU sensor makes the field work and post-processing relatively slower compared to the latest portable or wearable mobile scanners.

An additional constraint imposed on the students was that they needed to achieve the accuracy of the collected data at survey level, typically defined for scanning buildings indoors and outdoors for construction purposes at 1 cm. This primarily pertains to relative accuracy, whereas the absolute accuracy, the location and orientation of the model had lower requirements, considering the building's independent placement in a park-like environment; for this project, the general accuracy of typical RTK GNSS observation was required.

In summary, the collaboration between the Maihaugen Museum and the bachelor geomatics engineering program at NTNU in Gjøvik aligns well with the fundamental principles of hands-on education in geomatics. This agreement is based on the understanding that, as a general rule, students exhibit increased engagement and enthusiasm when their projects extend beyond the limits of the campus area (Stal et al., 2013).

3. Project implementation explained through the key features of PjB learning environments.

Project-based learning settings encompass six key features, as described by Krajcik and Shin, 2014 verbatim:

1. They start with a driving question, a problem to be solved.
2. They focus on learning goals that students are required to demonstrate mastery on key science standards and assessments.
3. Students explore the driving question by participating in scientific practices – processes of problem solving that are central to expert performance in the discipline. As students explore the driving question, they learn and apply important ideas in the discipline.
4. Students, teachers, and community members engage in collaborative activities to find solutions to the driving question. This mirrors the complex social situation of expert problem solving.
5. While engaged in the practices of science, students are scaffolded with learning technologies that help them participate in activities normally beyond their ability.
6. Students create a set of tangible products that address the driving question. These are shared artifacts, publicly accessible external representations of the class's learning.

Further, these key features will be used to give a report about the way the project was implemented and what positive outcomes were provided.

Feature 1: The Driving Question

The main driving question of the project revolved around maintaining accuracy while efficiently capturing detailed information for digital heritage documentation. Prerequisite knowledge was essential, requiring an understanding of technologies, sensors, error propagation, and control geometry. Varied backgrounds among participants necessitated preparatory sessions, including scanning practices (experimental learning) and additional lectures. This phase served not only to fill knowledge gaps but also to build a cohesive team.

The preparation time proved beneficial. Following the conclusion of the training phase and the detailed project announcement, the students independently formulated the main driving question swiftly during the planning phase.

Undoubtedly, the planning phase presented complexities, with students encountering successive challenges. Each solution necessitated the initiation of a driving question to gain a profound understanding of the specific problem at hand. While, in some instances, the teacher directed the questions, particularly in cases where clarification was needed, the team, especially when collaborating, adeptly recognized and addressed challenges independently and with notable efficiency.

Feature 2: Learning Goals and Assessment

The subject aimed to introduce students to terrestrial laser scanning and point clouds. Learning outcomes included understanding scanning technology, planning and executing projects, georeferencing methods, and statistical methods for QC of point cloud datasets.

As the subject was conducted in the final semester before students would embark on their bachelor thesis, it served an additional purpose: offering students the opportunity to apply previously acquired theoretical knowledge and practical skills, which may have been acquired during this project. The primary challenge presented by the project allowed students to integrate fragmented pieces of knowledge into cohesive and practical skills.

The project's assessment was seamlessly integrated into the subject's assessment structure. Alongside this project, students undertook various other tasks, delivering the results in a comprehensive final report at the conclusion of the active semester. While the project emphasized teamwork, there were individual tasks within it. The final portfolio, a culmination of individual contributions, was submitted individually. Students with an accepted portfolio were eligible to take the final exam.

Feature 3: Scientific Practice

Exploration of the driving question involved a multistep process, from planning to post-processing. Each stage required addressing challenges and finding solutions.

- Iterations of planning and field visit/inspection
- Several sessions of field work
    - Control network establishment
    - Outdoor scanning
    - Indoor scanning
- Several iterations of post-processing, quality control, and follow-up (gap filling) scanning
- Report writing

The exploration of the main question commenced during the planning stage, involving the design of the control network, choosing appropriate instruments and observation methods and selection of scanning stations; all aimed at addressing the challenges posed by the main driving question. The initial field visit prompted a reassessment and reconsideration of their ideas and solutions. Subsequent visits and phases of fieldwork introduced new challenges, such as an unstable floor in the building, unopenable doors/windows, and inaccessible areas, necessitating students to adjust their plans and devise innovative solutions. Additionally, weather conditions significantly influenced the planning of the fieldwork.

Figure 3. The log house and the Leica P40 scanner

The students' commitment to scientific practices was clearly demonstrated by the rigor of their methodology and its implementation.

Feature 4: Collaborative Activities

The collaboration involved a win-win arrangement between the subject coordinator, museum management, and students. This mutually beneficial collaboration offered a real-life project that can enhance student engagement in the learning process, while concurrently provide the museum with the chance to test a technology through this pilot initiative. This newly formed relationship serves as a solid foundation for connecting the local community to the internationalized university environment, fostering collaboration and shared benefits.

After the initial planning phase, during which all plans were worked out, the students established direct communication with the museum management. The subject/course coordinator limited his involvement to monitoring the communication, intervening minimally. Students efficiently organized logistics, equipment, schedule, and addressed special requests in complete synch with the management. This allowed students to hone on their management and logistics skills while experiencing the museum's management's appreciative and supportive approach, emphasizing the significance of their work. This collaboration provided students with valuable project management experience.

Feature 5: Scaffolded Learning Process

The learning process followed a scaffolded pattern, starting with supervised learning sessions and progressing toward more independent problem-solving. The gradual decrease in supervision demonstrated students' growing professional skills, problem-solving abilities, and self-confidence.

During the preparation phase, the subject instructor ensured that students acquired all the necessary technical and theoretical knowledge essential for understanding the challenges and commencing work on the project. Close supervision, at times reaching the level of micromanagement, was required during the training on the scanner and executing smaller scanning projects. The theoretical preparation included some lecture-type teaching sessions.

As the project moved into the planning phase, the teaching approach shifted towards question-based supervision, allowing students greater autonomy in finding solutions to the challenges they encountered.

During the fieldwork, after the initial phase where assistance was provided to start implementing their plans, students were gradually given more independence. Surprisingly early in the process, students demonstrated full autonomy in both technical tasks and related logistics and communication.

In the post-processing phase, only minimal interference was necessary. Students navigated and resolved challenges independently, driven by their complete engagement with the project.

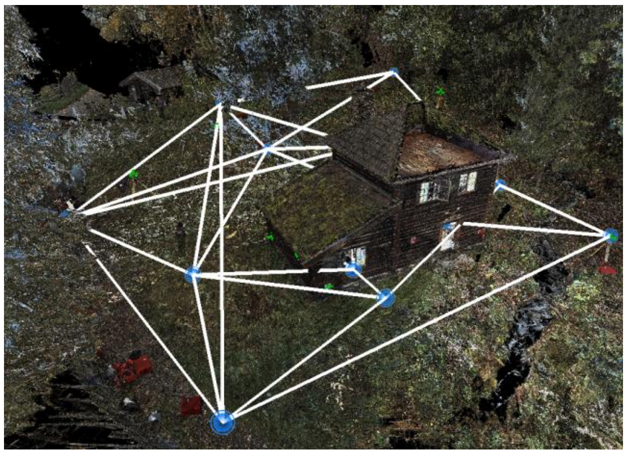

Figure 4. The registered point cloud with the links between scan stations

Feature 6: Tangible Products

The project yielded two tangible products: a registered, georeferenced point cloud and a comprehensive report. The point cloud, coupled with a quality control (QC) report, might serve:

- Decision making by the museum management
- Engineering design and subsequent implementation of the building relocation
- Educational purposes

- As reference for future testing of more efficient mobile scanning methods
- As a proof of concept for the management of the museum.

The report, emphasizing pedagogical value, helped students solidify connections between fragmented knowledge, transforming experiences into practical skills.

4. Summary of learning outcomes

The summary of tasks undertaken by students during this project-based learning session is depicted in Figure 5. These tasks can be categorized into three distinct phases: preparation, project execution, and deliverable preparation.

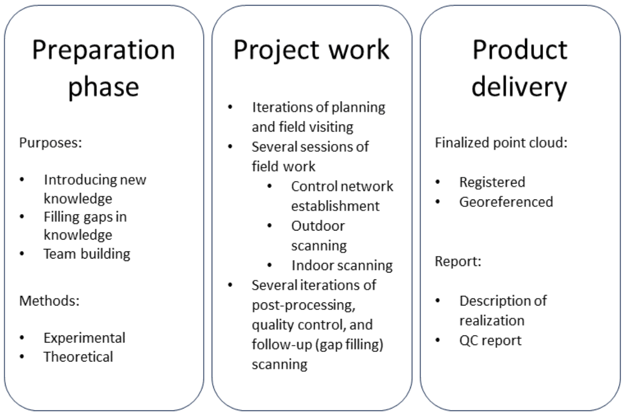

Figure 5. Overview of the phases of the project

In the preparation phase, students engaged in theoretical learning and practical experimentation, while also familiarizing themselves with collaborative teamwork dynamics.

Throughout the project execution phase, students delved into the intricacies of designing fieldwork procedures, conducting fieldwork operations, and iterating between these stages as necessary.

The final phase involved the preparation of deliverables. During this stage, students reflected on their actions, methodologies employed, and rationales behind their chosen approaches. The preparation of a quality report marked a pivotal moment in their journey towards becoming proficient engineers.

To assess the educational success of the project, an online questionnaire was administered to the participating students. The survey focused on various aspects, including the motivating factors of the project, the quality of communication among the parties, teamwork effectiveness, personal outcomes, and overall satisfaction. Using five-point Likert scales organized in matrices, multiple aspects of each topic were measured simultaneously, allowing for nuanced responses.

The survey was distributed via email to the students, ensuring honest responses through anonymity. To mitigate bias, the questionnaire was administered after students received their exam results. All six participants promptly responded within two days of receiving the invitation. The results, including median and mean values are presented in Tables 2-8. For questions marked with an asterisk (*), a value of 3 reflects a neutral opinion, while values lower than 3 indicate negative experiences and values higher than 3 indicate positive experiences.

Student Profiling

The questionnaire commenced with a profiling section aimed at capturing students' preferences regarding fieldwork, teamwork, hands-on challenges, theoretical engagement, project management, and problem-solving. These insights facilitated a more accurate interpretation of subsequent survey responses. For instance, negative ratings on teamwork had different implications depending on students' attitudes toward group work. The profiling will also serve as a valuable tool for designing teaching materials and activities, aligning with the expectations of bachelor geomatics students.

In this instance, their responses align closely with our expectations for bachelor geomatics students: they exhibit a preference for fieldwork and hands-on challenges over theoretical work, see Table 2. The fact that all students responded to every profiling question, despite having the option to opt out of any, demonstrates their openness and honesty in participating in the survey. Note that answering all remaining Likert Scale questions was compulsory.

How much do you like…	1	2	3	4	5	N	D	M
…fieldwork?	0	0	0	2	4	0	5	4.67
…teamwork?	0	1	1	3	1	0	4	3.67
…hands-on challenges?	0	0	0	2	4	0	5	4.67
…working with theories?	0	2	1	3	0	0	3.5	3.17
…managing projects?	0	0	1	2	3	0	4.5	4.33
…problem solving?	0	0	2	1	3	0	4.5	4.17

N: I would prefer not answering this question
D: Median
M: Mean

Table 2. Student profiling

Motivation

How motivating were the following ideas for you?	1	2	3	4	5	D	M
The idea of working outside the campus:	0	0	0	1	5	5	4.83
Contributing to a real word problem:	0	0	0	0	6	5	5.00
Contributing to the local community:	0	0	1	1	4	5	4.50
Contributing to a cultural heritage conservation project:	0	0	2	0	4	5	4.33

D: Median
M: Mean

Table 3. Motivation factors

Understanding students' motivations is essential for assessing project success. The primary motivator, as indicated in the Table 3, was the opportunity to contribute to real-world problem-solving. Additionally, while the students are STEM oriented versus humanities, the majority of participants expressed high motivation levels toward the cultural heritage preservation topic. We saw such examples earlier (Stal at al., 2013).

Communication

Effective communication is vital for successful teamwork. Assessing the quality of communication among project stakeholders revealed discrepancies, particularly in communication with the museum management, as two of the students expressed negative experiences, see Table 4. This result was surprising given the overall positive experience, with students receiving all the support they needed. A follow-up questionnaire shed light on possible reasons for the high variance in this feedback. While not every student was consistently involved in communication with museum management, all of them witnessed an incident in the field when an uninformed museum staff member questioned the students' activities, which must be a likely contributing factor to the mixed results here.

*How would you rate the communication between…	1	2	3	4	5	D	M
...you and your student fellows?	0	0	1	4	1	4	4.00
... the instructor and the team?	0	0	2	3	1	4	3.83
...the museum management and the team?	0	2	1	1	2	3.5	3.50

D: Median
M: Mean

Table 4. Communication

Teamwork

Different project phases create varying working environments that can influence teamwork dynamics. Fieldwork emerged as the smoothest phase, correlating with students' preference for hands-on activities. However, lower teamwork ratings in profiling correlated with negative experiences during certain phases of the group work. This suggests a need for enhanced team-building efforts during preparation (Table 5).

*How would you rate the smoothness of teamwork during the...	1	2	3	4	5	D	M
...preparation phase of the project?	0	1	3	2	0	3	3.17
...fieldwork?	0	0	0	4	2	4	4.33
...post-processing phase of the project?	0	2	1	3	0	3.5	3.17

D: Median
M: Mean

Table 5. Teamwork

Outcomes

Self-assessment of skill development highlighted the project's substantial impact on enhancing students' practical competencies and problem-solving abilities (Table 6), attributable to its intensive focus on fieldwork.

How would you rate the growing of your skills during the project?	1	2	3	4	5	D	M
Management skills:	0	0	3	3	0	3.5	3.50
Communication skills:	0	1	3	2	0	3	3.17
Hands-on skills:	0	0	1	1	4	5	4.50
Problem solving skills:	0	0	2	1	3	4.5	4.17

D: Median
M: Mean

Table 6. Students' self-assessment of skill development

Verdict

The two verdict questions, collected individually, emphasized their importance, and yielded positive responses, aligning with overall positive experiences reported by students, see Tables 7. and 8.

After fulfilling the project, how do you feel about it? Was it worth it?	1	2	3	4	5	D	M
Results:	0	0	1	2	3	4.5	4.33

D: Median
M: Mean

Table 7. Students' verdict

How strongly would you recommend launching a similar project for the next year's students?	1	2	3	4	5	D	M
Number of answers:	0	1	0	2	3	4.5	4.17

D: Median
M: Mean

Table 8. Students' recommendation

Students provided additional feedback through a text box, with four out of six offering comments. Suggestions included using mobile scanners for increased efficiency and addressing the project's time-consuming nature. While acknowledging the benefits of mobile scanners for efficiency, the current stationary terrestrial laser scanner remains effective for educational projects requiring complexity, opportunity for more control and high accuracy. Due to the students' rigorous use of this scanner, the created dataset will be an excellent material for future investigations as a reference dataset. Overall, students expressed satisfaction with the semester's content-rich learning experiences.

Finally, presented below are two additional comments obtained at the conclusion of the survey: "it was fun. I am very happy about the output and learning experiences from the course :)" and "Thank you for a nice and content-rich semester."

5. Conclusion and future

The described project experiences are based only on six students, and since it was implemented for the first time, the study is limited. Yet, the distribution of their answers in the evaluation phase clearly confirms the effectiveness of Project-based learning. The pedagogical success of this project and its impact on the students could be assessed through several additional metrics:

- Personal observation of their activities during the project
- The quality of content in their individually delivered reports
- The students' performance on the examination
- The students' performance in the next semester
- Feedback received in person
- Feedback provided through the questionnaire presented above.

Observing the students' growth in knowledge during their engagement with the project was particularly gratifying for the instructor. Witnessing the development of their self-confidence in decision-making and experiencing their moments of clarity when understanding phenomena within a broader context were gratifying. Their performance, as evidenced by assessment forms, such as examinations and delivered reports, underscored their comprehension of the subject matter within a larger framework. The questionnaire responses indicated overall satisfaction among the students while also highlighting areas for future improvement.

Based on the outcomes of this experiment, the plan is to continue implementing project-based teaching in the coming years. Several enhancements are warranted, including a stronger emphasis on team building during the preparation phase to enhance teamwork experiences. Additionally, incorporating a broader range of technologies, including the latest solutions, would be advantageous. The high-quality dataset generated this year will serve as valuable reference data for testing other technologies with improved productivity. Moreover, there will be a continued emphasis on proper quality control alongside efficient productivity, underscoring the role of engineers in this process.

Finally, while this particular implementation of the project-based learning method may have showed similarities with the problem-based learning method (PrBL), especially in terms of the students' freedom to define action steps, further development of this PjBL method could involve transforming it towards the PrBL approach (Gartner et al., 2022). Note that implementing the PrBL method in introductory courses might be challenging as indicated by Taboada et al. (2006) but partial integration is feasible (Gabela Majic et al., 2022).

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