Exploration labs: A high-quality PBL-format designed to equip students with career-critical competencies for industry

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Abstract

Project-based education is an established approach in engineering education to equip students with the necessary skills to address the highly complex and uncertain challenges they face in industry in a dynamic globalized industrial environment. The belief in the efficacy of project-based learning in conveying these skills has risen among educators, and a framework for designing effective, high-quality project-based learning formats has been proposed by Mergendoller (2018).
In this paper, a project-based learning format, the Exploration Lab, is introduced to address the research question: To what extent and through which elements does the EXL enhance career-critical competencies, and how do students compare it to traditional thesis projects? The format focuses on using real industry challenges to teach early-stage agile product development and innovation in an industry setting. The main elements of the format are described and linked to how they contribute to achieving high-quality project-based learning. Adding on this, a link to the ETH Competence Framework is made, elaborating on main competencies like problem-solving, critical thinking, collaboration, or communication the Exploration Lab aims to convey. Observations on key-learnings of the first cohort, including student self-assessments and industry outcomes, of this format are related to the competence framework, serving as initial validation of efficacy and highlight the Exploration Lab's alignment with high-quality project-based learning and competence-building goals.
In future works, more extensive approaches to measuring the effectiveness of this format could be explored. In particular, indicators of increased competence could be assessed using tools like pre- and post-project-participation surveys.

Introduction

Equipping students with the necessary tools and skills to overcome real-world challenges is increasingly recognized as a crucial aspect of modern education. The growing need for critical thinking, communication, and adaptability is essential for navigating highly complex and uncertain situations (Foster & Yaoyuneyong, 2016). Project-Based Learning (PBL) is a student-centered instructional approach that addresses these needs by emphasizing context-specific learning, active student involvement, and the achievement of goals through social interactions and the sharing of knowledge (Kokotsaki et al., 2016).

Shpeizer (2019) similarly observes that PBL offers a more engaging, learner-centered format that values autonomy, activity, and collaboration. Despite its potential benefits, the adoption and implementation of PBL in higher education have been gradual. One reason for this might be that linking project-based education not only to technical challenges, but to real industry innovations is extremely challenging, for example it requires a special environment with an industry partner who will allow students to actively work on their current challenges.

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However, despite slow adoption, the belief in PBL's efficacy is growing among educators worldwide, who see it as a means to help students master academic skills and content knowledge, develop future-oriented skills, and build personal agency for tackling life's and the world's challenges (Mergendoller, 2018). In this regard, an evaluation of Ngereja et al. (2020) showed that project-based assignments had a positive impact on student learning, motivation, and performance in both the short and long term.

Mergendoller (2018) highlight the increasing confusion about what constitutes high-quality PBL, proposing a framework that describes PBL in terms of student experience to provide educators with a shared basis for designing and implementing effective, high-quality PBL formats (HQPBL). The HQPBL-Framework states six required criteria, which are presented in the methods section.

While PBL itself is focused on how learning can be structured, one should not forget what should be learned; namely transferable skills and competencies. In this regard, La Cara et al. (2023) have recently published the ETH Competence Framework, contributing to the debate on why and how universities change to prepare future-ready graduates. This framework allows categorization of 20 transferable skills into the subject-specific, method-specific, social, and personal competencies.

Scope and research question

This paper examines the Exploration Lab (EXL), a program evaluated during its initial run from October 2023 to April 2024. Conducted through a collaboration between the ETH Feasibility Lab and Bühler AG in Uzwil, it involved eight ETH Zurich students from diverse fields. The study investigates the question: To what extent and through which elements does the EXL enhance career-critical competencies, and how do students compare it to traditional thesis projects?

The analysis is structured in three parts. First, we identify which components of EXL align with the six criteria of effective project-based learning, as outlined in the HQPBL framework. Second, using the ETH Competence Framework, we map how these components contribute to students' skill development. Third, a survey of all participants provides data on their self-reported skill levels before and after the program, as well as their views on EXL versus traditional thesis formats.

Background on organizing institution: ETH Feasibility Lab

The ETH Feasibility Lab was founded in 2019 by Prof. Mirko Meboldt and Dr. Stephan Fox from the Product Development Group Zurich, Department of Mechanical and Process Engineering, ETH Zürich, Switzerland. The lab aims to connect cutting-edge ETH technologies with market demands.

Many bold ideas are often dismissed as too risky for traditional industry commitments and too undefined to attract specific research interest. This 'Valley of Uncertainty' results in many ideas not being tested. The lab aims to reduce uncertainty with minimal resources, allowing innovative concepts to bridge this gap and qualify for further development. In this ecosystem, students act as 'know-how carriers,' learning to navigate early-stage innovation projects and launch their professional careers.

Initially, the lab conducted individual projects with one student working on a project for a single company. This phase resulted in foundational learnings that informed the development of the Lab's methodology for projects with high uncertainty.

Exploration Lab: A new PBL approach integrated with industry

From 2023 to 2024, the ‘Exploration Lab’ (EXL) format emerged, scaling project-based learning (PBL) to involve student teams exploring multiple ideas for a single company. New methods were developed to prioritize ideas based on initial testing outcomes.

Looking ahead, the Feasibility Lab seeks to expand the EXL’s student pool and interdisciplinarity, inviting more companies to engage in exploratory projects or innovate in areas lacking defined expertise. Committed to inclusivity, the ETH Feasibility Lab refines its innovation methods and formats using continuous insights. The second cohort launched in October 2024, running until March 2025, with a 6-person lead team, 14 students, and 4 industry partners. The EXL framework is detailed in the sections below.

Mission and core principles

Building on the students’ curiosity, we respectfully challenge the status quo and co-create innovations to inspire an agile exploration mindset among our partners.

At the core of the format is student curiosity, which acts as the primary filter through which all ideas and actions must pass. A strong focus is placed on validating ideas through experiments and rapid prototyping. The students are trusted to make informed decisions, based on the hypothesis that their curiosity is guided by relevant considerations, such as the viability, desirability and feasibility of the proposed projects. Additionally, students are empowered to debate all assumptions, with project leaders advocating for this right and aligning expectations with industry partners. This involves stepping outside our partners’ standard procedures and processes to explore new possibilities and innovative solutions. Teamwork and stakeholder involvement are maximized to leverage diverse perspectives and our partners’ expertise to enrich the innovation process. The team is united behind these principles, enabling it to resist being confined to traditional processes and thereby able to not only live but also inspire a culture of continuous exploration.

Team composition and structure

The team consisted of eight students with backgrounds in mechanical engineering and materials science. Among them, one was working on a bachelor’s thesis, one on a master’s internship, and six on their master’s theses. The students were native speakers of German, Italian, and French, comprising one woman and seven men, aged between 20 and 30 years. The lead team comprised three individuals, each either holding a PhD in product development or having relevant professional experience in the field, all with startup experience.

The legal framework established an agreement for the program’s execution without predefined technical projects. The idea generation and identification as well as the selection of suitable projects were integral parts of the project and students’ mandate. Decision-making authority on what to work on rested with the student team and the lead team, not the company. This setup ensured that students only worked on projects that interested them, teaching them to allocate resources to promising projects and make decisions independently. To maximize stakeholder interaction, the agreement required the team to be on-site at least three days a week. This facilitated the flow of information and enabled spontaneous meetings with stakeholders.

Program overview

A broad timeline of pre-phase, main phases, and post-phase is shown in Table 1. The main phase of the program spans 26 weeks and is tailored to fit a masters’ thesis. Students start into the program by familiarizing themselves with the methodology and partner companies, actively shaping the idea finding process. An exploration phase of 17 weeks allows rapid iteration on multiple topics, with the goal to find an individual deep-dive topic for in-depth work in the last phase.

	Timeframe	Activities	Involved Parties
Pre-Phase	July-September 3 months before start	Recruiting students, partner coordination, initial funnel Ideation	Lead team, partner companies
Ramp-Up	October **3 weeks**	Methodology introduction, familiarize with partners, ideate	Students, lead team partner stakeholders
Exploration Phase	October-February **17 weeks**	Rapid iteration (Powerthink, Hack, Sprint) on many topics	Students, lead team, partner stakeholders
Deep-Dive	February-March **4 weeks**	Individual, in-depth work on individually chosen topic	Students, lead team, partner stakeholders
Wrap-Up	March **2 weeks**	Report-writing, presentation	Students, lead team, partner stakeholders
Post-Phase	April 2-4 weeks	Grading of reports, administrative closing tasks	Lead team

Table 1: Project Phases of Exploration Lab - Total Project-Duration for Students: 26 Weeks (6 Months Full-Time).

Program-level methodology: Innovation cascade

The innovation cascade in the Exploration Lab is designed to make small initial investments when uncertainty is high and progressively larger investments as uncertainty decreases. Frequent Go/No-Go decisions are implemented to isolate the best ideas and stop working on less promising ones, allowing only the most viable projects to move forward.
The cascade consists of increasingly large micro-projects called 'Treatments' (see Figure 1):

- **Powerthink**: *Is it worth pursuing? What is the critical function?*
  A 90-minute workshop, involving stakeholders from the partner organization. This stage focuses on structuring the problem, identifying the core issue, and brainstorming potential solutions. (Total pre- & post-processing time: 4h)
- **Hackathon**: *What are potential solutions for the critical function?*
  A one-day event, where the team conducts research and rapid, low-fidelity implementation and testing of potential solutions. This provides a first approximation of their feasibility.
- **Sprint**: *Can we test the critical rapidly and validate the approach?*
  A 3.5-day project, to develop minimal but functional prototypes. This stage evaluates the feasibility of different approaches through practical implementation.
- **Deep Dive**: *Can we solve the minimal set of functions to test the business case?*
  A four-week focused project with individual work, where the documentation serves as a written document for the thesis. This stage involves thorough exploration and development of the chosen solution.

Projects should only advance sequentially through the stages: Powerthink to Hackathon, Hackathon to Sprint, and Sprint to Deep Dive. However, treatment stages can be repeated or revisited as needed. This focuses efforts on the most critical questions and deliberately leaving out less important aspects, thus avoiding overcomplication and reducing the risk of failing to achieve set goals.

The Exploration Lab's structured week design was iteratively refined to balance divergent and convergent activities, maximize uninterrupted development time, reinforce learnings, and ensure efficient planning and coordination. The final structure, shown in Tabl, optimizes both deep work and collaborative alignment.

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Build & assemble experiment	Analyze results	Idea generation	Retrospective, planning	Build, define focus
Afternoon	Experiment, get data	Stakeholder update, document results	Idea Generation	Prioritize, experiment design	Build, experiment
Treatment Type	Sprint	Sprint	2x Powerthink or 1x Hack	Retro / Buffer Sprint (½ Day)	Sprint

Table 2: Week Structure of Exploration Lab (Project Management).

Each week began on Thursday with a one-hour retrospective, where students reflected on key learnings, challenges, and potential improvements from the previous cycle. Following this, they self-organized into small project teams (2–3 members), selecting sprint treatments aligned with their interests and expertise. From Thursday to Tuesday noon, teams worked intensively on these treatments, ensuring uninterrupted problem-solving and rapid iteration. Tuesday afternoons were dedicated to presenting findings to industry stakeholders, facilitating external feedback and decision-making. Wednesdays were allocated for Powerthink and Hackathon treatments, enabling focused ideation and rapid feasibility testing before transitioning into the next iteration.

Topic-level methodology: The Five Finger Formula

The ambiguity and fuzziness of the early-stage innovation phase is extremely challenging. In this phase, it is especially important that all decisions in the process should be based on data and not only on assumptions and gut feelings.

To achieve this, the Five Finger Formula is the tool we teach to participants in the EXL to navigate high uncertainty and achieve initial results without a large budget. It fosters the optimization of 'learning efficiency' - minimizing resources spent on dead-end paths, thereby maximizing attempts to find viable solutions. Additionally, it serves a 'common language' to structure the early-stage innovation process and ensure consistent communication. The five principles of the formula are easily remembered by the first letters of each finger's name: T, I, M, R, L. An in-depth description of this method, including application examples, is provided by von Petersdorff-Campen (2024) with a quick overview in Figure 2. This tool is supplemented by various commonly known methods (e.g. Design-Thinking, Lean-Startup) on a case-by-case basis.

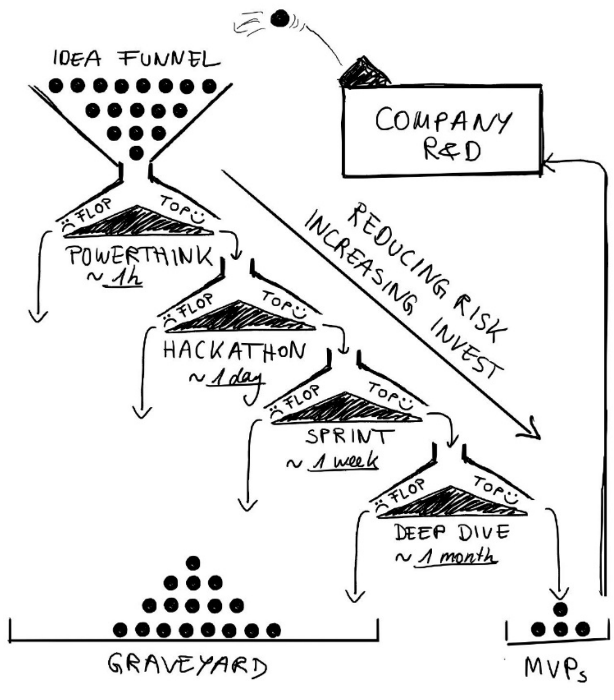

Figure 1: Idea Management System - Innovation Cascade. The innovation cascade serves as a guide to timebox project increments, with time and resource investments increasing as project risk is decreased. Decision gates at every stage serve to filter out less promising ideas and focus on the most promising ones.

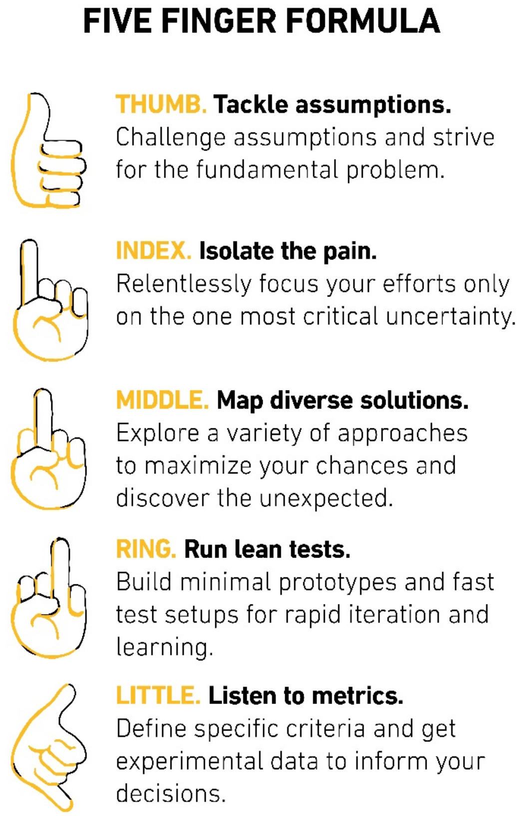

Figure 2: Uncertainty Management Method: Five-Finger Formula.
The Five-Finger Formula acts as a mnemonic aid to help remember key focus areas at various project stages of projects with high uncertainty.

Methods

The impact of the Exploration Lab format on competence development is assessed in the following three ways:

Mapping of EXL program elements to HQPBL framework

According to the HQPBL framework by Mergendoller (2018), a PBL format must fulfill six factors to be considered 'high-quality' in terms of the students' learning experience and by extension competence development. The fulfillment of these factors is evaluated based on a structured list of EXL framework elements. The factors are:

- **Intellectual Challenge and Accomplishment**: Students learn deeply, think critically, and strive for excellence.
- **Authenticity**: Students work on projects that are meaningful and relevant to their culture, their lives, and their future.
- **Public Product**: Students' work is publicly displayed, discussed, and critiqued.
- **Collaboration**: Students collaborate with other students in person or online and/or receive guidance from adult mentors and experts.
- **Project Management**: Students use a project management process that enables them to proceed effectively from project initiation to completion.
- **Reflection**: Students reflect on their work and their learning throughout the project.

Mapping of EXL program elements to ETH Competence Framework

The ETH Competence Framework by La Cara et al. (2023) defines 20 competencies categorized into four domains: subject-specific, method-specific, social, and personal. To assess the relevance of competencies fostered in EXL, the lead team systematically reviewed all 20 competencies and identified up to four relevant links for each framework condition item.

Evaluating student learning outcomes and reflections

All eight participating students completed a survey to self-assess their competence levels pre-thesis and competence gains afterwards. Additionally, they were asked to compare the EXL to a traditional thesis (see Tabl for differences). Finally, each student also submitted a personal learning report reflecting on their key takeaways from EXL. These reports were analyzed in relation to the ETH Competence Framework, with notable observations highlighted.

Traditional Thesis	Thesis within Exploration Lab
Single topic	Multiple topics
Individual work	2/3 Team collaboration, 1/3 individual work
Academic setting (Majority)	Industry setting

Table 3: Key differences of thesis within EXL compared to a traditional thesis. Multiple topics are explored in a team-setting in industry.

Results

Mapping of EXL program elements to HQPBL framework

The EXL covers each of the HQPBL framework's factors in multiple ways, (see also Table 4 left column):

- **Intellectual Challenge and Accomplishment:** The topics are unsolved real industry challenges. Some have been unsolved for many years, making it challenging and leading to accomplishment when delivering results.
- **Authenticity:** The EXL is fully immersed in industry, thus the challenges we encounter are both authentic and immediately relevant. In this real-world context students see the direct impact and relevance of their work on a daily basis.
- **Public Product:** The work of students is critiqued and discussed with stakeholders, the lead, and other students on a weekly basis.
- **Collaboration:** The EXL requires students to work together extensively. For most of the project duration (four months), students collaborate on shared projects in teams of 2-3 people.
- **Project Management**: Students take responsibility for scheduling their update presentations as well as organize and plan their own tasks for the week, taking over project management duties.
- **Reflection**: Weekly and monthly retrospective sessions with the team ensure continuous reflection on the students' progress and learning.

Mapping of EXL framework elements to ETH Competence Framework

The competencies we believe are promoted most are shown in the right column of Table 4.

- **Subject-specific:** 2 competencies addressed through 10 elements
  These are required throughout the project but are explicitly mapped to only one EXL element – namely, the use of industry-standard tools to address challenges.
- **Method-specific:** 5 competencies addressed through 9 elements
  Multiple elements map to method-specific competencies. For example, frequent decision-making based on test-results, or the application of project-management methods are associated with the competencies analytical competencies, decision-making, and problem-solving.
- **Social**: 7 competencies addressed through 10 elements
  Many EXL elements relate to social competencies, particularly in the context of collaboration. Working in teams of 2-4 students and engaging frequently with stakeholders, supervisors, and customers provide opportunities to develop communication, cooperation and teamwork, and customer orientation.

- **Personal:** 6 competencies addressed through 14 elements
  Personal competencies in EXL are fostered through structured reflection, feedback, and autonomous decision-making. Key elements linked to these competencies include peer feedback sessions, individual coaching, stakeholder presentations, and self-directed project management.

Evaluating student learning outcomes and reflections

Student reflections

Due to confidentiality, project-specific details in the students' reflections are omitted. Student reflections were mapped to the same competence descriptors as EXL elements, summarized below in Table 5 and shown in Table 6.

	Present in # of Reports	Total Items	Competence Breakdown
Subject-specific	1	1	Techniques & technologies (1)
Method-specific	7	16	Decision making (6), analytical competencies (5), problem-solving (4), project-management (1)
Social	7	11	Communication (4), cooperation & teamwork (4), leadership & responsibility (2), customer orientation (1)
Personal	7	13	Critical thinking (3), adaptability & flexibility (3), self-direction & self-management (3), integrity & work ethics (3), creative thinking (1)

Table 5: Breakdown of Mapped Competence Descriptors in Students' Learning Reports.

Student survey

Figure 3 presents self-assessed competence ratings before and after the thesis. The left column displays pre-thesis ratings, from -3 (very weak) to +3 (very strong).
Problem-solving, together with cooperation & teamwork show a consistently strong rating (median +2, strong). Self-presentation & social influence shows the lowest median pre-thesis rating. Project-management also ranks weakly, with a median of 0 (average) but with a large spread (-2 to +3).

The right column shows the corresponding post-thesis competence changes, from -3 (significantly declined) to +3 (significantly improved). The largest median post-thesis improvements are observed in problem-solving (+2), project-management (+2), creative thinking (+2), and critical thinking (+2). No competencies show a negative change post-thesis. The smallest improvement is observed for sensitivity to diversity (+0.5) and integrity & work ethics (+1).

When asked to compare EXL to a traditional master's thesis, students unanimously ranked it as 'more engaging', 'more fun', and 'more motivating'. Additionally, seven out of eight students felt better prepared for industry. Finally, there was unanimous agreement that EXL offers more opportunities for personal growth. The complete results are shown in Figure 4.

HQPBL Framework	Elements of the Exploration Lab Format	ETH Competence Framework	
Intellectual Challenge and Accomplishment	Work on open, high-uncertainty topics.	Problem-solving	Critical thinking
	High autonomy in project management and stakeholder communication.	Communication Leadership & responsibility	Self-awareness & self-reflection Decision-making
	High commitment to create impact and quality results expected.	Integrity & work ethics	Self-direction & self-management
Authenticity	Work on commercially relevant topics proposed by industry partner.	Problem-solving	Customer orientation
	Students largely self-organize their choice of project and their activities.	Cooperation & teamwork Leadership & responsibility	Adaptability & flexibility Project-management
	Use of tool & process ecosystem of industry partner. (e.g. CAD, Python Programming)	Techniques & technologies	Concepts & theories
Public Product	Regular presentations to industry stakeholders incl. to C-level management.	Critical thinking Self-awareness & self-reflection	Media & digital technologies
	Daily presentations of progress to peers & supervisors.	Self-presentation & social influence	Integrity & work ethics
	Focus on frequent interaction with users/customers.	Communication Customer orientation	Sensitivity to diversity Negotiation

Subject specific | Method specific | Social | Personal

Table 4: Mapping of EXL Framework Elements (Middle Column) to the HQPBL Framework (Left Column) and Mapping to Competencies of the ETH Competence Framework (Right Column). Continued on the next page.

HQPBL Framework	Elements of the Exploration Lab format	ETH Competence Framework	
Collaboration	Teamwork of 2-4 people.	Communication	Adaptability & flexibility
	Regular shuffle of team composition.	Leadership & responsibility	Integrity & work ethics
	Close involvement of and co-working with industry partners. (e.g. Stakeholder)	Communication	Negotiation
Project Management	Autonomy in choice of topics and activities through multiple topic stages.	Project-management	Self-direction & self-management
	Frequent decision making based on test results is expected.	Decision-making Project-management	Creative thinking
	Application of project management and innovation methodology is expected.	Analytical competencies Critical thinking	Adaptability & flexibility
Reflection	Weekly team retrospectives on learnings, working mode and methodologies.	Self-direction & self-management	Self-presentation & social influence
	Bi-Weekly individual coaching sessions with student supervisors.	Project-management	Self-direction & self-management
	Regular moderated peer feedback sessions.	Leadership & responsibility Sensitivity to diversity	Self-awareness & self-reflection

Subject specific   Method specific   Social   Personal

	Quotes from students' written learning observations	ETH Competence Framework
1	Isolating the pain revealed that there was an underlying grand vision by one of the stakeholders. I finally truly understood where the uncertainties are and what is critical for success.	Analytical competencies Problem-solving Communication Critical thinking
2	Being able to engage with our potential customers early in the development process has helped shape the path forward. I learned about the importance of not asking, 'What is the goal?' but rather, 'What is the problem?'	Decision-making Communication Critical thinking Problem-solving Customer orientation Analytical competencies
3	Being precise and understanding the problem before diving into Critical Function definitions is essential. As the project moves forward (...) it becomes necessary to redefine the Critical Function to shift focus onto the areas of highest uncertainty. They're (Methodology Frameworks) never a one-size-fits-all solution. Engaging in discussions with the team and being open to be challenged on the Critical Function are crucial in finding a 'good' or the 'right' Critical Function.	Analytical competencies Decision-making Problem-solving Adaptability & flexibility Self-direction & self-management Decision-making Project-management Communication Cooperation & teamwork
4	Projects are almost never developed in vacuum; very often it is people rather than technical issues that will determine the success of a project.	Techniques & technologies Communication Cooperation & teamwork
	The fact that there wasn't a predefined goal meant need-finding of what we even want to achieve was a fundamental part of our work every week. I learned how to find my way through a fog of uncertainty, how to figure out what our next step will be without even (fully) knowing where you're going yet.	Decision-making Adaptability & flexibility Problem-solving Integrity & work ethics Analytical competencies Self-direction & self-management
6	In situations where uncertainties still exist, individuals often shy away from making decisions, preferring to pass 'the hot potato of responsibility' to others, avoiding holding it themselves.	Cooperation & teamwork Integrity & work ethics Leadership & responsibility Decision-making
7	A key aspect of our collaboration is the ability to bring new perspectives to existing problems as an external team. Unbiased and without the operational blindness that can arise from long-term industry affiliation, we were able to develop fresh approaches and ideas.	Analytical competencies Critical thinking Cooperation & teamwork Creative thinking
8	Making countless micro-decisions is important for high velocity innovation. Be persistent and don't get too attached to your ideas, be willing to pivot depending on what the data shows. If you want something, step up and take initiative.	Decision-making Integrity & work ethics Self-direction & self-management Adaptability & flexibility Leadership &

Subject specific | Method specific | Social | Personal

Table 6: Quotes from Students' Learning Observations Mapped to Relevant Competencies of the ETH Competence Framework.

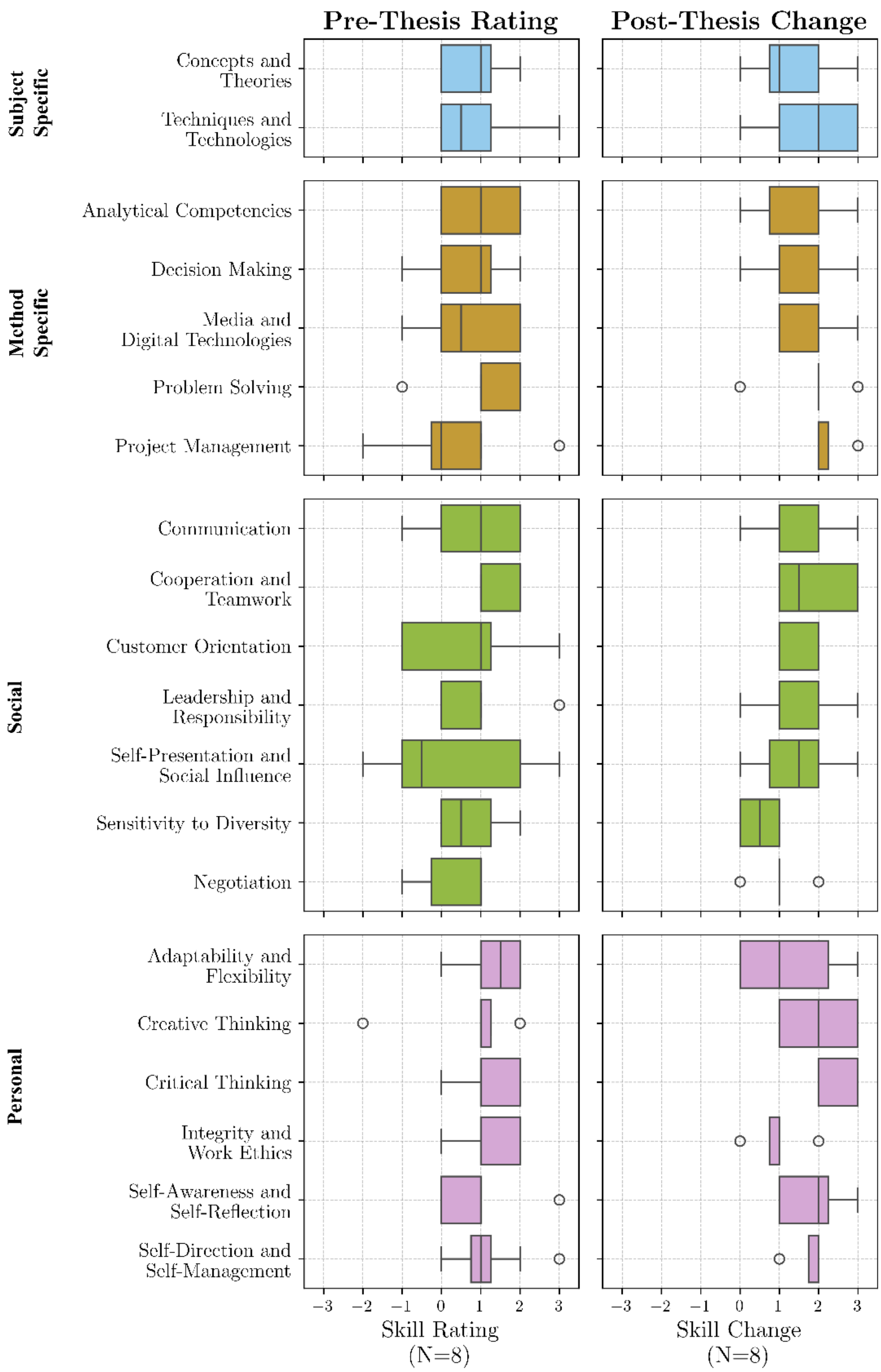

Figure 3: Student Responses to Survey on Competence Development During EXL. Left: Self-assessed pre-thesis competence rating, ranging from -3 (very weak) to +3 (very strong), sorted by competence category. Right: Self-assessed post-thesis competency change, ranging from -3 (decreased significantly) to +3 (increased significantly).

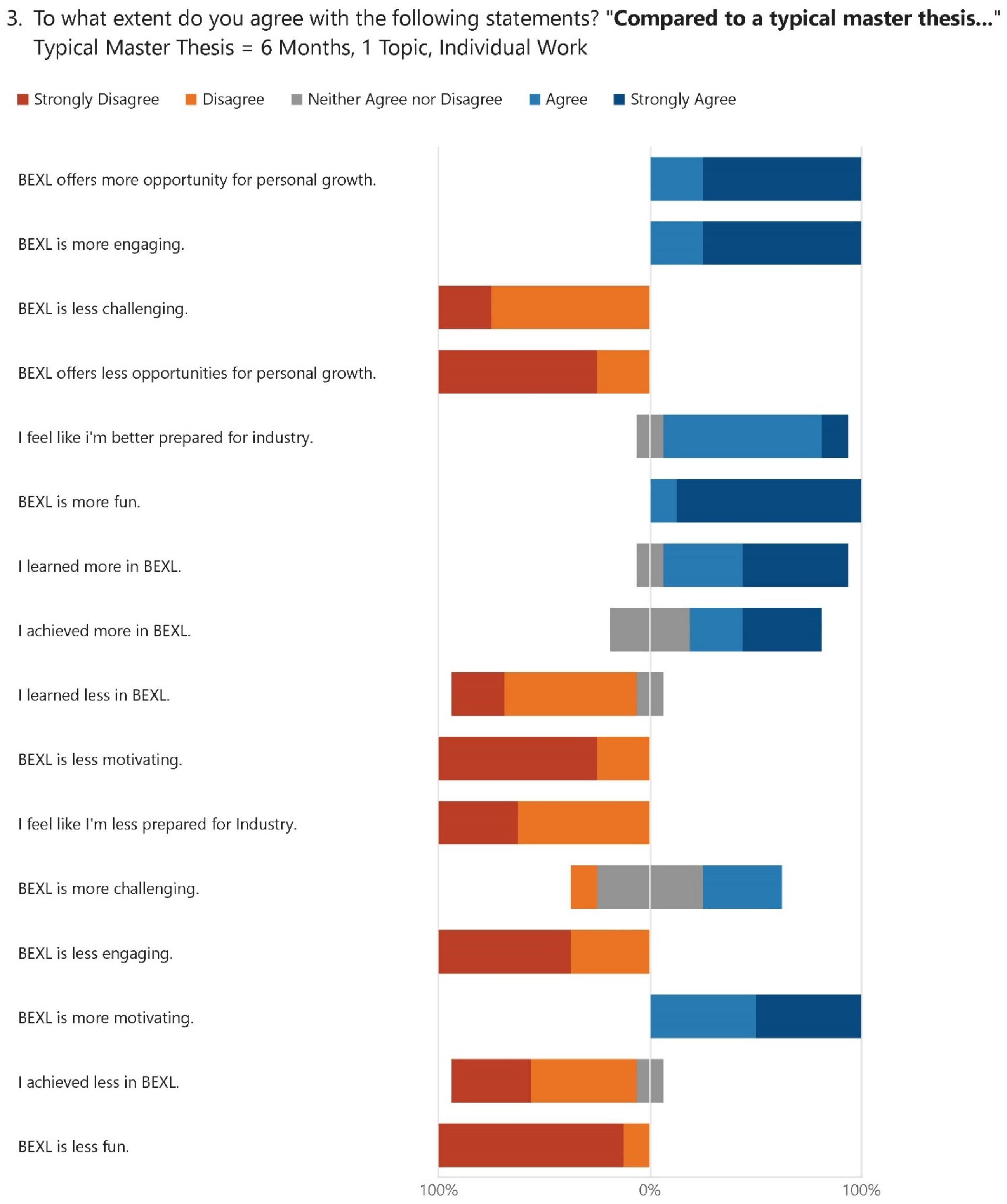

Figure 4: Student-Survey Results: Comparison of EXL to traditional (master) thesis. Note: BEXL is equivalent to our use of EXL, but reflects an old name, the B relating to Bühler AG.

Discussion

The EXL's real-world immersion and team-based approach appear to be highly effective in equipping students with essential skills like critical thinking, communication and adaptability. These skills, which Foster & Yaoyuneyong (2016) have shown to be critical for navigating highly complex and uncertain real-world challenges, may be career-critical in their later occupation. By mapping student outcomes to both the HQPBL criteria and the ETH Competence Framework, we observed that EXL fosters active engagement, practical experience, and industry-oriented skill development:

Mapping of EXL program elements to HQPBL framework

The EXL format addresses each of the HQPBL factors: Intellectual Challenge, Authenticity, Public Product, Collaboration, Project Management, and Reflection. Working on unsolved problems not only enhances intellectual rigor but also gives students a sense of accomplishment upon delivering tangible outcomes. The authenticity of the challenges faced allows students to see the immediate impact of their work. Frequent feedback accelerated competence development, and over time, students' independence increased, managing decisions and defending project strategies with minimal guidance. These findings align with broader PBL research, which shows real-world immersion encourages deeper, more transferable learning of e.g. problem-solving, communication, and adaptability. (Kokotsaki et al., 2016).

Furthermore, how often and in what way individual students sought feedback varied greatly. While some sought targeted input regarding both technical and personal skill development, others primarily requested topic-specific feedback. This difference underscores the importance of offering multiple feedback options - both formal and ad hoc - so that students can tailor their learning experience to meet their own developmental needs.

Overall, aligning EXL elements with HQPBL principles supports our hypothesis that EXL is a highly promising, high-quality PBL-experience fostering multiple dimensions of competence development.

Mapping of EXL program elements to ETH Competence Framework

Mapping of EXL's core elements against the ETH Competence Framework reveals broad coverage across subject-specific, method-specific, social, and personal domains. Subject-specific competencies are not tied to specific elements, except the required use of industry-standard tools by partners. As the EXL is intended as masters thesis, we accept this apparent lack of targeted development - subject-specific competencies are expected to be present from the students' preceding studies.

In contrast, method-specific competencies - fully supported by nine EXL elements -highlight the program's hands-on nature, and techniques like the Five-Finger Formula reinforce analytical, decision-making, and problem-solving skills.

Social competencies develop through team collaboration and regular stakeholder interactions, sharpening communication, customer orientation, and cooperative decision-making.
Personal competencies are fostered via reflection sessions, individual coaching, and self-directed project management, building autonomy and self-awareness. These gains were particularly salient during the latter stages of the thesis, when students began exercising higher levels of independent judgment and initiative.

Student learning outcomes and reflections

The individual learnings reports have students citing meaningful improvements in method-specific competencies (decision-making, analytical competencies, problem-solving), social competencies (communication, cooperation, leadership), as well as personal competencies (critical thinking, adaptability, self-direction). In parallel, the self-assessed survey shows the most pronounced competence gain for problem-solving, project management, and critical thinking. This shows that students' perspectives greatly overlap with our expectations of fostered competencies of EXL.

When comparing the students views of a traditional thesis compared to EXL, students unanimously found EXL more engaging, fun, and motivating, which we see as a strong indicator for efficacy of the format – a passionate, motivated team will perform much better and develop faster in comparison to a setting where team-spirit and motivation is lacking. Additionally, the fact that most participants felt better prepared for industry supports our intention of a purpose-built PBL-format to bridge the transition from academia to industry.

Observations on student development: Lead team perspective

The lead team (of which the authors are part of) is closely involved in the day-to-day supervision of the student, and thus was able to collect a diverse range of subjective observations on how different feedback mechanisms influenced the students and their development throughout the thesis. The most significant observations are shared as anecdotal evidence:

- The close supervision of students in early phases is crucial for the adoption of our methodology. Early on, short feedback loops are a key-enabler for effective competence development.
- As the project went on, students' independence significantly increased. In the second half of their thesis, students required noticeably fewer supervisor inputs and independently pushed decisions, took ownership and defended their approach.
- Students' behaviour in how they process feedback and ask for input varied drastically. Some students very proactively asked for specific feedback and guidance regarding competency and skill development. Others were more focused on topic-specific feedback rather than personal development.

Key-success factors & long-term sustainability of EXL

To ease the implementation of similar formats, we highlight once more the most important points. We believe these broad, overarching factors are paramount for creating an experience that is beneficial for all involved parties, and to enable long-term success:

- **Clear Legal Framework**: Establish a flexible legal framework early to address IP concerns and lower stakeholder engagement barriers. Ideally, all IP should transfer to the industry partner.
- **Open Problem Statements**: Partner companies should provide problem statements with open-ended solutions rather than rigid requirements. Students can be more innovative when allowed to explore freely.
- **Student Curiosity**: Allowing students to choose their topics ensures their motivation, which directly impacts project success.
- **Consistent Student Support**: While the methods are simple, consistent application is crucial. Senior support helps students stay on track with agile methods, especially when facing company resistance.
- **Ongoing Stakeholder Engagement**: Continuous communication with stakeholders ensures project handover and integration into the company, preventing the project from being sidelined.

In addition, we believe two final aspects must be fulfilled for long-term feasibility:

- First, supervision and coaching are critical for the success of initiatives like EXL. To scale the program, we need a pipeline of former students who are able to move into lead-team roles, leveraging their network and experience to mentor new participants, and shaping future iterations of EXL.
- Second, long-term partnerships and industry-demand for EXL is required. This is dependent on partners' being satisfied with the collaboration with ETH in the context of EXL and thus being open and willing to commit to future participation in EXL.

Conclusion & outlook

Summarizing, the results show that real-world immersion and team-based structures can cultivate a wide range of method-specific, social, and personal competencies, aligning with HQPBL principles. We see thorough coverage when mapping EXL framework elements to the ETH Competence Framework, from analytical thinking and problem-solving to communication and self-management. The student reflections and survey further confirm that EXL boosts motivation and industry readiness while explicitly enhancing project management and critical thinking skills, among multiple others. This synergy of authentic challenges, structured feedback, and team collaboration demonstrates a strong path for bridging academic objectives with professional practice.

We believe there is strong initial evidence for EXL presenting as an effective high-quality PBL-format, fostering a multitude of competencies through its many facets. The initial cohort has reported significant learnings, while the results of the second cohort are still pending. In conclusion, EXL appears to effectively enhance students' competencies, leading to motivated, adaptable graduates which are well-prepared for modern work environments.

Future work

We advocate for making project-based learning experiences on corporate innovation accessible to all students to better prepare them for their careers and to enhance the innovation capabilities of our workforce.

For a successful format to have a lasting and significant impact, there must be a setup that ensures continuity and scalability. Many factors need to be considered to achieve this, a selection of which we have outlined in the discussion: The learning outcomes for students are crucial. Industry partners must see tangible benefits, to continue providing students with access to real-world problems.

Continuous improvement should be the goal. In this regard, we acknowledge that the current conclusions are drawn on limited data of only eight participants' self-reported learnings, opinions, and our assessments. It is thus of even greater importance to conduct additional research on the efficacy of the Exploration Lab and similar formats. In future studies, a baseline measurement of other formats and traditional theses should be included, while expanding the pool of participants in EXL. This may lead to gaining a better understanding of success-factors of early-stage innovation and educating students on innovation methodology, and in turn pave the way for more PBL-Formats of high-quality and efficacy – for educating the innovators of tomorrow.

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