Cormier, L., & Turcotte, M.-C. (2026, June 13–17). Embedding Engineering Design Across Courses in an Integrated Mechanical Engineering Work-Study Curriculum [conference paper]. Proceedings of the Canadian Engineering Education Association, Moncton, NB, Canada. https://doi.org/10.24908/pceea.2026.21568 CC BY-NC 4.0

EMBEDDING ENGINEERING DESIGN ACROSS COURSES IN AN INTEGRATED MECHANICAL ENGINEERING WORK-STUDY CURRICULUM

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Abstract – *This paper presents the redesign of several engineering design learning activities within a new and unique work-integrated mechanical engineering program structured around an extended on-the-job component. Early cohorts highlighted gaps in student preparedness for the large scale, open-ended capstone projects conducted in an industrial environment. These challenges were linked to limitations in the timing and structure of previous Design Process and Methodology training, students' difficulty in recognizing their own biases and limitations, and misaligned expectations between academic and industrial supervisors. Drawing on Fink's taxonomy of significant learning, experiential learning principles, and structured reflective practice, a set of coordinated changes was implemented across two third-year courses. These changes included an inverted classroom design activity, a peer-based critical review exercise, revised term projects emphasizing continuity across courses, and enhanced formative planning and design review steps. Preliminary feedback from students, professors, academic advisors, and industrial supervisors suggests that the new framework improves students' integration of design knowledge, strengthens their problem-solving capabilities, and enhances self-awareness in the design process. Remaining challenges related to workload perception and the evolving impact of generative artificial intelligence on assessment practices are discussed. Overall, the redesigned trajectory provides a better preparation for the engineering students to undertake complex industrial design mandates while reinforcing the program's experiential learning philosophy.*

Keywords: Capstone Project, Reflective Practice, Significant Learning, DUAL, Engineering Design.

1. INTRODUCTION

Fostering opportunities for engineering students to integrate their newly built knowledge into skills and competencies that extend across their courses, over their whole curriculum, and into their future professional practice is a challenge for any university department. Although a program approach to engineering curricula is widespread in Canadian universities, in practice, the burden lies on individual teaching persons to facilitate this outcome.

This paper describes an initiative to promote a design mindset and refine design skills prior to the Capstone Project (CP) at the Université du Québec à Trois-Rivières' Drummondville Campus undergraduate degree in Mechanical Engineering (ME) by integrating design activities across two courses and promoting the reflective practice of engineering. The particular context of the program and of the limitations to be addressed are first discussed. The project's objectives and the specific changes to the courses are then detailed. Finally, specific and general outcomes for students and faculty are discussed.

2. CONTEXT

Most Canadian engineering programs now incorporate a diverse set of experiential learning opportunities. Many of these are provided through industrial visits, laboratory assignments, Co-op internships (CI) within industrial or research environments, as well as CP. These experiential learning opportunities are often very consequential for students, since they provide an authentic learning experience of the engineer's professional practice.

In 2017, the Université du Québec à Trois-Rivières opened a new campus in Drummondville (UQTR-DR). Among the program offerings is a new undergraduate program in ME. Providing an authentic learning experience is an explicit objective of the ME undergraduate program at UQTR-DR. As such, it is built on a distinctive integrated work-study model that is unique in Canada. After two full-time summer CI, students who opt in to this optional program called DUAL spend their final two years embedded within an industrial partner. Currently, the program enrolls small cohorts averaging a little over

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twenty new students per year, almost all of which opt-in the DUAL.

Figure 1 presents the structure of the DUAL program. This DUAL program is based on a conventional Co-op structure with three mandatory, full-time, summer work terms, with a first CI unit starting from the third term (year 1, term 3: Y1T3). From the sixth term on, the program is structured around a continued presence of the students within a host industrial partner (Y2T3 – Y4T2). For these last two years, where conventional Co-op programs would feature course terms, the DUAL pathway features a course load over three weekdays and on-the-job training for the remaining two weekdays.

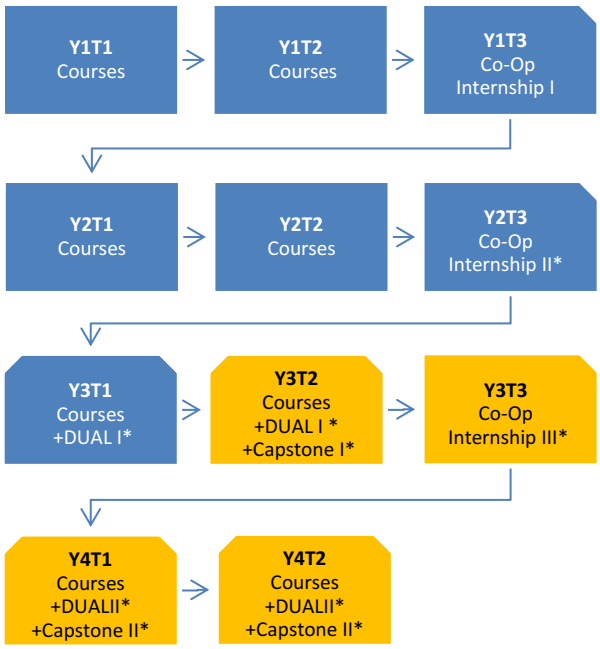


Figure 1 : DUAL pathway program structure. Activities noted with a * are all hosted by the same industrial partner for a given student. A single cut corner indicates CI, double cut corners indicate DUAL, and orange indicates CP.

This on-the-job training consists of four main activities: the two courses (DUAL I and DUAL II) themselves and the two activities related to the capstone project (CP I and CP II). This immersion enables an exceptional experiential learning opportunity: a four-semester CP conducted in a workplace setting, supported by individual methodological coaching from an academic advisor and technical supervision from industry specialists [1, 2].

The DUAL I and DUAL II activities are centred on the soft skills that are required to navigate the complex world of engineering (communication, ethics, law, environmental issues, etc.), while the CP I and CP II focus on the Design Process and Methodology (DP&M).

A reflective practice of engineering is built in the program, through journaling exercises and frequent discussions with the academic advisor. Innovations of the program, such as a structured integration of the reflective practice in engineering, are further discussed in [1, 2].

This experience exposes engineering students to the open-ended nature of real-world engineering design problems, particularly through the CP. Like all engineering programs, the mechanical engineering undergraduate degree at UQTR-DR scaffolds the acquisition of the graduate attributes required to handle such a large project across the curriculum. Yet, when our first cohort entered the DUAL program, three limitations quickly became apparent:

- L1 The historical way of introducing the DP&M did not adequately prepare engineering students for the scale of the new framework of the CP. Due to their inexperience, engineering students do not have the ability to properly assess the workload and responsibilities associated with their real life industrial application CP.
- L2 The continuous presence of the engineering intern over almost two years often leads them to an "in-between" status, being neither a regular intern nor a regular employee at the industrial partner. The professional engineers that supervise engineering interns in their DUAL and CP activities, despite being highly competent and appreciated by the interns, have little comparable experience in managing interns in the context of a large-scale engineering project, which, moreover, includes methodological inputs from an academic advisor. This results in occasional misalignments of the expectations from each side about the level of methodological and technical coaching expected from them.
- L3 The engineering students do not recognize their lack of preparation by themselves. Their initial engineering education and exposure to the DP&M made them overconfident in their abilities to handle their mandate. Academic advisor feedback is not sufficient to counter their optimistic perceptions.

Although point L2 is more a communication and support issue than a program-level issue, elements L1 and L3 are much more directly actionable. Acknowledging these limitations, the teaching team was brought to redesign several learning activities, and many of these changes are discussed here.

It is important to realize that, from a theoretical standpoint, those three remarks point towards some form of the well-documented Dunning-Kruger effect [3], the existence of unrecognized biases among engineering students [4], and that these biases are known to exist among students [5]. These theoretical concepts are therefore mobilized into a process akin to the engineers' DP&M

approach to set pedagogic objectives and identify practical changes to meet them.

The first cohort from 2017 entered the DUAL and CP courses in late 2019 and graduated in 2021. Quickly, a reflective journal was incorporated into the DUAL courses (academic year 2020-2021). The reflective journal facilitated discussions between students and academic advisors and partially addressed L2 and L3. A detailed discussion about this initiative is detailed in [2]. From the academic year 2020-2021, a set of coordinated changes was implemented across two third-year courses to further address the identified limitations. These changes included an inverted classroom design activity, a peer-based critical review exercise, revised term projects emphasizing continuity across courses, and enhanced formative planning and design review steps as well as additional reflective exercises. This paper focuses on the practical changes made to this pair of courses from Y3T1, although a brief description of the integration of these changes among other initiatives is also included.

3. METHODS

Initially, graduate attributes and the DP&M were introduced across several courses from the second term. Most notably, formal teaching of DP&M materials and a larger design project were included in the *Mechanics of Machines* course (problem definition and design brief) and the *Design of Machine Elements* course (conceptualization and final design methods), in Y3T1. A more advanced DP&M course followed in Y3T2, as part of the CP kickoff.

However, despite the short time between these activities and the CP, many engineering students struggled to connect the coursework and project experience with their CP. This lack of connection made it hard for them to mobilize their experience into properly planned actions and hindered their project's progress. Moreover, and perhaps most importantly, the students did not appear to gain significant awareness of their failings despite continuous academic advisor feedback.

This prompted an interrogation among the academic advisors and the persons teaching the design courses and a redesign of the learning trajectory without altering the program's overall structure was proposed as an initial solution. From a general perspective, the redesign is aimed at easing the engineering students' transition into their role as designers, while minimizing administrative changes and maintaining high standards. The hypothesis is that applying Fink's taxonomy of significant learning [6] to structure the design components of the Y3T1 courses, and integrating experiential learning opportunities [7] and reflective practice [8], would foster deeper, more effective, and significant learning at marginal cost.

In the proposed framework, Fink's significant learning experience is defined as one that transforms the learner's perspective on the world. It is reached through six categories of experiences (foundational knowledge, application, integration, human dimension, caring, and learning how to learn), which are leveraged by experiential learning opportunities and reflective practice approaches.

This paper focuses on practical changes made to a pair of courses from Y3T1, namely the *Mechanics of Machines* course and *Design of Machine Elements* course. A brief description of the integration of these changes among other initiatives is also included.

3.1. Approach

Several specific objectives were devised for supporting the changes.

- O1. Improving the learning experience.
- O2. Fostering a continuum perspective on the learning process.
- O3. Reinforcing the problem-solving skills of engineering students faced with open-ended problems.
- O4. Developing metacognitive capacities to recognize bias and limitations.

The assumptions are that experiential learning opportunities and reflective practices are very effective tools to promote the significant learning experience and achieve O1-O3, while the reflective practice and continuous academic advisor support promote the realization of O4.

Changes were introduced to the course mechanics to translate those approaches and objectives into actionable items. The changes involved targeted syllabus adjustments, mainly falling under three categories and all promoting an aligned pedagogy:

- Cat.1 Changes in course material delivery and timing.
- Cat.2 Redefinitions of assessment objectives.
- Cat.3 Reformulation of exercises and assessments to meet the new objectives.

Table 1 provides a summary of course changes as well as of the related objectives and change categories. The first major change in the courses touched all three categories and primarily targeted improving the learning experience (O1) and fostering a continuum perspective (O2). In particular, the attainment of O2 rests heavily on leveraging possibilities emerging from the fact that course contents of the *Mechanics of Machines* and *Design of Machine Elements* courses are highly complementary and that both courses are given to the same cohort in the same semester. The objectives are thus attained by providing new collaborative activities overlapping both courses. These activities focus on learning, applying and reflecting on the application of the DP&M in a practical situation.

Formerly, the respective DP&M content in each course was covered in a specific, three hours long, class meeting and the knowledge was directly applied as part of an end-of-term project.

In the new course structure, an inverted classroom activity is developed in which:

- DP&M training is delivered through online videos before group activities.
- In week two, the schedule is rearranged so that periods from both courses are combined to provide a six-hour design activity, where small teams develop a design brief and conceptual solution for a real-world, human-centred problem.

During the design activity, professors provide active feedback on the DP&M application and broader issues such as subjectivity, bias, values, ethics, leadership, and ownership of design choices. This activity provides an authentic learning experience and the very active discussions include a large reflective component in which students are required to self assess and are given a lot of constructive feedback.

Table 1: Summary of course changes.

Change	Objectives	Categories
Inverted classroom design activity overlapping across two courses (same semester)	O1, O2	Cat.1-3
Peer based critical review exercise of a previous year's project	O2, O4	Cat.2, 3
Revised term projects emphasizing continuity across courses, and enhanced formative planning and design review steps	O1, O4	Cat.2, 3
Structured reflective exercises	O1, O2, O4	Cat.1-3

Second, as part of the *Design of Machine Elements* course, and also mobilizing the concept of the reflective practice of engineering, teams of students are asked to provide a constructive critical review of a previous year's end-of-term project. This critical review is structured around the DP&M theory and their own experience. In this exercise, each statement they make about the reviewed project needs to be demonstrated by arguments and examples. The teams are also asked to discuss their experience of reviewing other students' work and to identify good practices that they discovered in the critically reviewed projects, as well as practices that they do themselves and that they found to negatively impact the project report. Alternative practices are then suggested as part of the critical evaluation. By encouraging reflective practice, by reaching over two courses and also by using materials created by peers from a previous cohort, objectives O2 and O4 are promoted.

The end-of-term projects are also completely reworked to reinforce open-ended problem-solving skills (O3), while also emphasizing the continuity of the curriculum (O2), promoting reflective practices (O4) and improving students' learning experience (O1).

While initially, projects in the two courses covered the whole design process, they have been reworked to bring a more specific focus on each course's learning objectives. The end-of-term project of the *Mechanics of Machines* course now focuses on the design brief, specification definition and conceptual design, while the *Design of Machine Elements* course's end-of-term project starts from a basic specification and has the students work on a conceptual design and then refine it into a final design.

An important aspect of these projects is that while they are specific to each course, they share a common project context that is maintained year after year, even though the specific design projects of each cohort are different in each course.

The project's context is a detailed description of an industrial process typical of many industries. It describes a continuous processing line that operates on a membrane that is transformed in the process. The process line includes an unwinder, membrane accumulators, idler rolls, a processing section and a rewinder. Several structural, safety, operational and physical constraints are provided. Among the design projects that have been assigned up until now are:

- Follower slither for cutting the membrane
- Membrane accumulators (allowing continuous processing and storage during winding roll changes)
- Winder transmission
- Winder autoloader/unloader

As the two courses are normally taken by the same students in the same semester, project teams are shared for the two courses (note that students are encouraged to form different teams for the reversed classroom exercise).

The projects for both courses are presented as two parallel projects that are led by the design teams. In both courses, projects are defined so that the teams need to consider the possible impacts of their design choices in one project on the other.

To support the students in their design, a planning report with extensive feedback from the professor is required prior to moving forward towards the projects' final objectives. In the case of the *Design of Machine Elements* course, this takes the form of a mini design review meeting where diverse aspects of the team's proposal are reviewed collectively in a guided, in-class activity, with direct feedback. Teams are then required to submit an updated proposal report that includes their responses to comments obtained during the design review before moving on to the final design phase.

Finally, at the end of the semester, an extensive reflective questionnaire on the teams' experience is part of the end-of-term project assessment. In this reflective

questionnaire, students individually and collectively discuss the strengths and contributions of each team member in regards to initial expectations, the suitability of resources used to plan and produce the end-of-term project, and discuss ways of improving their individual and collective output and team work abilities.

It is important to note that the reversed classroom activity and the mini design review are purely formative, while the critical review, the project plans, and the end-of-term projects are summative. Also worth noting, for these summative evaluations, a significant fraction of the grading is explicitly linked to indicators of the graduate attributes.

In addition to the initiative already discussed here and in [1, 2], several small changes fostering the cultural changes associated with O1 to O4 have also been implemented. Among those, the most noteworthy are:

- Evaluating internships is based on the demonstration of significant learning outcomes.
- Mixing different internship levels during end of term oral presentations. At each level the oral presentation objective evolves from learning about oneself, towards learning about the profession and finally thinking about one's professional goals.
- Scaffolding the DP&M design course with direct reference to prior activities described here.

3.2. Evaluation

This paper describes work that was performed as part of continuous program improvement efforts rather than as a formal research project. The authors are fully aware that although this provides a lot of flexibility and opportunities, it limits the generalization potential of any conclusions that come out of the work.

However, the very peculiar nature of the ME program at UQTR-DR, with very small cohorts ranging from five to fifteen students in their third year, and a history only going back to 2017, would have limited the power of any formal approach.

Therefore, the project's outcomes have been evaluated through direct feedback from teachers, students and CI supervisors during the courses and subsequent CP. The direct feedback is gathered from:

- Reflective journals;
- Team work reflective exercises;
- CP meetings;
- Program development workgroup;
- Institutional program assessment survey;
- Personal communications.

It is worth remembering that students only experience one version of the curriculum, while teachers, professors and industrial supervisors may have experiences across the evolution of the framework.

4. OUTCOMES AND DISCUSSION

The project aimed at improving the learning experience of students throughout the DUAL and CP experience, to foster a continuum perspective on the learning process, to reinforce the problem-solving skills of engineering students faced with open-ended problems and to develop metacognitive capacities to recognize bias and limitations. Feedback from industrial CI and CP supervisors, students and faculty was obtained for specific efforts as well as at the general program level. The experience of all parties during the DUAL and CP as well as the general outcomes of the CP and reflective journals are the main proxies for assessing the improvement of the program relative to the project's objectives.

The most significant remarks from industrial internships and CP supervisors' experiences will be discussed first, followed by students' commentaries and finally, perceptions from academic advisors and professors are shared.

Industrial supervisors are somewhat removed from the changes performed in our program as compared to the students and their academic advisors and professors. However, they often have experience with interns from different programs and are most aware of the current expectations of the industry towards their new hires. Therefore, their experience with the DUAL framework provides significant insight into our program's qualities and limitations. The most significant comment we receive from industrial supervisors regarding interns from our program is that they tend to score high in their professionalism, adaptability and autonomy, as compared to interns from other programs. This is in line with objective O4 and O3. The structured reflective practice, the integration of knowledge and competencies across courses, and the increased contact with academic advisors and faculty are all actions that were intended to improve these aptitudes. Other factors that may also contribute to this perception are the longer exposure of the supervisors to the interns and the additional support from academic advisors that interns from other programs do not enjoy at the same level. By promoting the reflective practice of engineering and contacts with real-world applications, other activities that are part of the program and that are aligned with this project's objectives may also contribute. These are discussed further in [1, 2].

From the students' perspective, the reversed classroom design activity is highly appreciated and provides a practical introduction to the DP&M. In doing so, it improves the students' sense of preparedness for their end-of-term project and CP.

However, students report that the current supporting videos rely on a reference that has now been updated and for which the terminology has somewhat evolved. Even though an annex is provided to address the change of wording, students strongly desire a reviewed version of the

online videos. This perspective is shared by professors and academic advisors, underlining the importance and difficulty of maintaining up-to-date support material for such activities.

Another shared perspective between the professors and the students is that the reversed classroom activity is too dense for the allotted time. Lots of time is spent on the problem definition and discussions about the importance of biases and human factors in the design process. Students develop an interest in the project as it goes, but oftentimes, the ideation and evaluation phases are too short, and the students feel like their work was cut out just as they are getting to the interesting part.

These two remarks underline important takeaways that can be generalized to most inverted classroom activities. Despite their very high potential for a significant learning experience, it is difficult to maintain up-to-date course materials, particularly videos, when the subject evolves. Also, the more actively the students participate, the more important and difficult it is to maintain a balanced schedule, within the activity, but also with other more conventional class schedules.

The critical review exercise is often seen as confidence building by students. They value the opportunity to access peers' work where they can recognize some of their own weaknesses and benchmark themselves in a constructive process. The critical review therefore serves as a stepping stone for the end-of-term project, which is itself another step towards the CP.

Students consistently value the authenticity of real-world end-of-term projects and CP, describing them as their first genuine encounters with open-ended design problems.

However, despite the efforts to ensure that the assignments between the two courses are clearly distinguished, students find it difficult to understand the specific expectations of each course. Many teams therefore find the project to be very stressful and since both projects share the same context, their perception of the workload is magnified.

Despite the students' perceptions and worries, in practice, the professors find that the students deliver projects that are well aligned with the respective mandates of each course. Part of this is attributed to the formal planning step and mini design review that is now part of the projects' deliverables.

In general, academic advisors report that the redesign enhances knowledge integration and early awareness of challenges, leading to richer discussions with advisors later in the CP. Students, academic advisors and teachers also appreciate the direct contact promoted by the integration of reflective practice in several aspects of the evaluation.

Therefore, given the generally positive outcome of this project on the perception by all parties of student preparedness for their CP, and by extension, for their professional practice, the authors suggest that the combination of reflective practice and knowledge integration across courses and within experiential learning opportunities be considered by other instructors as a means to promote pedagogic alignment towards course objectives. Furthermore, maximizing collaborative activities across courses by teaching teams also appears to be an interesting way to promote a program mindset and break silos in the student and teacher community.

It is also worth noting that, in the context of the emerging generative artificial intelligence, the reflective practice and one-on-one exchanges promoted by the reflective practice provide a unique learning and assessment opportunity where the student experience is discussed directly. This limits the possibility of misusing artificial intelligence tools in assessments. It is also a practice that is likely to promote agency in academic and workplace environments. The authors therefore recommend other instructors to explore this type of evaluation within their assessment structures.

Generative artificial intelligence, however, poses risks to some more conventional assignments, like the critical review or planning phases of the projects. Instructors should take the time to construct their assignments in a way that promotes the use of artificial tools in an ethical manner that supports professional and personal integrity.

Specifically, to address challenges and opportunities related to generative artificial intelligence for the current initiatives, the department of mechanical engineering is preparing a follow-up project that will reinforce the actual framework and integrate the ethical use of artificial intelligence in engineering design. The reflective practice of engineering again promotes vibrant exchanges on the topic between faculties and students.

5. CONCLUSIONS

In deploying a new program with a strong experiential learning component, the Department of mechanical engineering at the Université du Québec à Trois-Rivières' Drummondville campus was confronted with some shortcomings in the initial staggering of the engineering design graduate's attributes and in the teaching of the design process and methods. These shortcomings were most visible in the capstone project, which is a significant design project pursued in an industrial environment as part of each student's individualized, on-the-job, training framework.

To address these discrepancies, program changes operated at the classroom level were applied. These changes relied on Fink's taxonomy of significant learning experience, complemented by a reflective practice and experiential learning paradigms to guide changes in formative and summative assessment practices.

Specific objectives pursued by these changes are: improving the learning experience, fostering a continuum perspective on the learning process, reinforcing the

problem-solving skills of engineering students faced with open-ended problems, and developing metacognitive capacities to recognize bias and limitations.

Direct feedback from the community suggests that the changes are well aligned with the objectives. Integrating the reflective practice and across courses activities that promote knowledge and competency integration in a pedagogically aligned context, therefore, appears to promote students' development towards their future professional practice and an increased awareness of the challenges related to managing real-life, open-ended engineering projects relying on the design practice and methodology.

Nevertheless, some challenges remain and the program improvement work will continue. Among the most significant of those challenges is the new requirement for adapting the pedagogy and the assessment methods to the reality of generative artificial intelligence. Sometimes, conflicting requirements for adapting the classroom pedagogy and learning outcomes assessment, while maintaining a balanced workload for both faculties and students, and maintaining up-to-date course materials, is a tough balancing act.

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Acknowledgements

The authors would like to show gratitude to all the students, faculties and administrators of UQTR, as well as Drummondville's exceptional community, for providing such an exceptional Petri dish for engineering education.

Disclosure Statement

Artificial Intelligence Tool: Microsoft Copilot (the Université du Québec à Trois-Rivières' institutional instance); Conceptualization: Copilot was used to find references related to the project in the scientific literature; Data Collection Methods: No usage; Data Analysis: No usage; Privacy and Security: no identifiable data was shared with Copilot for this study; Writing—Review & Editing: Copilot was used to provide improvements to the final submission's language; Project Administration: No usage.