A DIVE INTO DESIGN INTEGRATION CHALLENGES FOR 1ST YEAR ENGINEERING STUDENTS

Abstract – Since 2010, Polytechnique Montréal offers the Aerospace Engineering four-year program. The introductory project “AER1110 - projet initial en génie aérospatial” is proposed to first year students who have completed a single semester.

This course applies an innovative approach with better alignment with critical competencies identified by the aerospace industry. Among the course objectives, students learn and apply mechanical design methodology in an authentic design-build-test experience inspired from professional engineering design practice. This paper describes the motivations, framework and the characteristics of this course to achieve an effective project based learning experience inspired from industry practice for students.

An “ask – don’t tell” approach is taken so project activities are built to generate open-ended questions to be answered instead of using knowledge learned from other courses to be applied on predefined problems.

Multiple iterations of this introduction to engineering project have been tried. Until now, most experiences had significant flaws: authenticity, high student uncertainty, motivation, assessment alignment with professional practice objectives, competition versus collaboration, etc. From all these iterations, a robust project framework has evolved.

Teaching staff implication to build authentic project experiences is significant and can overwhelm academic systems rapidly. A step by step approach can manage the time issue, but to achieve the integration competency objective a more profound academic system transformation is needed that includes: assessment methods review, course load management, course systems and student-mentor interactions.

Keywords: Integration, Project based learning, Introduction to engineering, Aerospace.

1. INTRODUCTION

In 2010, Polytechnique Montréal started the Aerospace Engineering four-year program. This new program proposed students a study path that gave an aerospace context to the content given while still providing solid general theoretical grounds.

The program provides specific aerospace content to students: Flight mechanics, aircraft structures, control systems, propulsion, and aerodynamics. Included in the program were four team projects (one per year) and a minimum of one required internship period in industry

(maximum of four). This program is aligned with the CEAB (Canadian Engineering Accreditation Board) graduate attributes [4] and also applies the CDIO initiative concepts and practices [3].

Among the four team projects in the curriculum, the introductory cornerstone project “AER1110-projet initial en génie aérospatial” is of peculiar significance. It is proposed to first year students who have completed a single semester. The major goals as educators in this project course are to enable students to get, as early as possible, a better understanding of the design engineer’s role and responsibilities within the aerospace industry in order to both increase their motivation, make links with past and future courses in the curriculum and discover better practices to develop.

The basic project learning activity is based on the “Introduction to mechanical engineering” project. Over time, specific elements were introduced to differentiate the activities to better match industrial design process practices specific to each field of work. Teaching for professional practice is stated as the central lesson in Passow’s [7] review of competencies in undergraduate engineering programs. Practice is defined as the “complex, creative, responsible, contextually grounded activities that define the work of engineers at its best”. The project course evolution started from this industrially grounded context to teaching.

Linked to this grounded context, according to Viau [8], student motivation can be fostered by building a learning activity that:

1. Is significant in the student’s eyes
2. Is diversified and integrated to other activities
3. Gives a significant challenge
4. Provides an authentic experience
5. Requires a cognitive engagement by the student
6. Makes the student responsible by giving choices to be made
7. Permits students to interact and collaborate with others
8. Integrates an interdisciplinary character
9. Has clear guidelines
10. Provides sufficient time to accomplish tasks

A well-constructed project based learning experience can deliver on all these indicators.

Also, as reported by Freeman [5] an “ask – don’t tell” approach may promote increases in student performance. The project activities are built to generate open-ended questions to be answered. From the first day in class team participants are preselected by the teaching staff to promote

diversity in the team (interests, competencies, technical abilities, experiences, and task preferences) based on a self-reported survey of personal perceptions on these elements. Teams are then challenged for a given aerospace mission to: identify and analyse needs; design a flying device; manufacture and demonstrate functionalities of their product; respect quality criteria; measure performance and calculate project cost and margins. The project experience goes through the complete product design cycle, leverages team dynamics and explores the financial and management aspects of project work.

The project is completed in 13 weeks and is divided in three major milestones:

1. Stakeholder needs analysis and characteristics specifications of the product to design. For this, students sequentially progress from the needs to the prioritized functions and specifications using the Houses of Quality model.
2. Search for ideas, concept selection and rationally supported solution proposal

Technical analysis of the retained solution and building of a prototype. (While electronics parts may be purchased, additive manufacturing (3D printing) is imposed to produce the structural parts of the prototype). A final test and performance demonstration is done in the 12th week. In week 13, teams share their feedback, explain and justify gaps between their computations and performance results and present the lessons learned.

Ethical and professional behaviours are highlighted and reinforced by several self and peer evaluations. Self evaluation is applied by the team/company to measure and assess their prototype characteristics and performance during the mission demonstration. Peer evaluations must be supported with documented feedback and the results affect individual summative evaluations. Further, practicing aerospace engineers share with the teams their professional project experiences through direct in class mentoring over the 13-week project timeline. Student teams also benefit from the direct support of human resource experts in teamwork, problem-solving and leadership.

One essential objective that evolved over time is to further develop integration competencies. Compared to the educational environment (e.g. university), in industry, “integration” refers to the relationship between functions, stakeholders, suppliers; to address and solve interfaces issues in order to realize a product or project rather than individual learning and personal knowledge integration. The competence development of “industrial integration” is achieved by grouping 3 to 4 teams in single companies in order to merge sub-assembly solutions developed in parallel by these different teams into a final complete prototype able to perform an imposed mission. The challenges imposed by this structure generates: cooperation, inter-teams friction, negotiations, problem solving, trade-offs and rational decision making abilities;

all needed to improve integration competencies. This is also an opportunity for these teams to celebrate the success obtained by their respective companies when the prototype achieves the original objectives.

Another essential objective is to expose the teams to several “project reviews” where the teaching staff acts as industrial project executives. This input enables the teams to perform design iterations and benefit from their peers learning and sharing.

2. MULTIPLE ITERATIONS OF THE PROJECT ACTIVITY

Multiple iterations of the project structure in the last 4 years were required to obtain the expected level of integration competencies, they are detailed in the following sections.

2.1. Generation 0, Standard team project

In the standard first year cornerstone project, teams complete a design project in a single semester. The end result is to document the final solution in a detailed report. Final report evaluations were almost never discussed with students since they were submitted during the last class of the semester, no final face to face retroaction was given.

Another important project deliverable is to build a prototype to demonstrate the functionality of the proposed design. The testing is performed during the last course in an informal competition between student teams.

Integration challenges were limited in this project format (Fig. 1). Each team managed all project elements in a small easily manageable group of 6 to 7 students. Formal project management structures even if presented were not used significantly for lack of added value to the teams.

Motor	Control	Structure
Aerospace team 1		

Fig. 1. Project structure, generation 0.

2.2. Generation 1, disciplinary teams

The first project structure iteration is for aerospace students only. Nine independent teams were divided to work on three functional systems in parallel taken from the same mission statement. The functional systems (motor, control and structure) were defined by the teaching staff. In the last few weeks, one team for each system (3 total) are combined together to form a company. From the 9 initial teams, 3 companies are formed. Each company continues development of an integrated complete solution that will be tested in a competition between all the companies (Fig. 2 and 3).

Fig. 2. Project structure, generation 1.

Fig. 3. Delivered prototype.

Although the companies all developed functional prototypes, the integration process did not involve the required complexity to simulate industrial challenges. Small disciplinary teams demonstrated a potential for integration challenges but did not deliver a complete experience.

2.3. Generation 2, consultancy model

A project structure simulating a consultancy model is used. Aerospace and mechanical engineering student teams are assigned a specific subsystem required for the imposed mission of a drone delivery system.

After specialized work for a few weeks four Mechanical and Aerospace Engineering teams (one per subsystem) are joined into a single “company”. All subsystems are then further developed and modified to become an integrated product (Fig. 4 and 5).

Fig. 4. Project structure, generation 2.

Fig. 5. Delivered prototype of drone and base station.

The payload system combined a mechanism to land and a system to pick up a load (egg, soda can, and canned food).

The drone then had to transport this load along a predefined path and accomplish tasks.

The proposed project team structure generated an “us and them” dynamic. Disciplinary divisions took over problem solving. A common simple interface between systems was not managed or designed correctly in all companies. The proposed structure did not generate by default the necessary level of integration and negotiations to achieve the objective.

2.4. Generation 3, partially integrated teams

To achieve further disciplinary integration the Aerospace and Mechanical engineering students are partially integrated in functional teams on a common project. Each function sees the interaction between two disciplinary teams. The mission is loosely based on Boeing’s GoFly [1] and NASA’s UAM (Urban Air Mobility) Grand Challenge [6] call for proposals. This structure demanded many administrative adjustments but keeps the academic group divisions (grading, teams, class assignments) between Aerospace and Mechanical engineering (Fig. 6).

Fig. 6. Project structure, generation 3.

Fig. 7. Drone with lifting mechanism

The applied project structure generated the best product results to date (Fig. 7). All systems were functional and performed the planned mission. Product integration was functional but better design integration still remains possible. The course administration remains a barrier to further integration, it will be the next challenge to tackle.

2.5. Generation 4, fully integrated teams

The next step is to further integrate the Aerospace and Mechanical engineering students earlier in the process by breaking the academic administrative boundaries between the groups (Fig. 8). The student teams become in complete integration on a common project, members in a single team come from both disciplines. The proposed project mission is based on flight based alternatives for public transit in densely populated areas.

Fig. 8. Project structure, generation 4.

Fig. 9. 2019-Prototypes, generation 4.
Mission performed

Fig. 10. 2020-3D design,
Prototypes not materialized and mission not tested

The energy required to build the academic support around this integration is very significant. Course content, websites, assessments, deliverables all need to be redefined and managed. The large number of students (105 total) and the limited capacity of the two training rooms required the use of more technology and real time communication tools. The rooms are now setup with ad-hoc systems of cameras and loudspeakers to share lectures and presentations between the two training rooms.

In winter 2020, the project was realized but adjusted and limited due to the sanitary constraints. Teams forming companies had to design the product responding to the imposed mission but without prototype building and testing.

As anticipated, we noticed a better transparency between engineering disciplines. Virtual meetings were managed efficiently within teams and in their respective company.

During winter 2021, due to Covid 19 sanitary constraints forced to deliver all classes virtually. Based on shared experiences, new students expressed disappointments not having the chance to perform

prototype testing as in previous years. This feedback is positive for us and confirms the high level of motivation of our students for this project.

Information is being compiled to better optimize the benefits on the project results versus the energy required by the teaching staff to put the structure into place. In 2021, considering socio-sanitary limitations due to COVID 19, the students were participating virtually to all course activities. They also were invited to provide detailed instructions along with their parts/sub-assemblies, for the teaching staff to assemble, for them, their company's prototype. This very important technical documentation is a requirement in projects that is often underestimated and poorly documented while the prototype usually gets more energy from the team since it is the result of a more captivating, sometimes last minute, trial and error approach. These imposed requirements put more focus on documentation, communication, Health and Safety, and student's professional responsibilities to suppliers and other project operation functions than usual in student projects.

3. RESULTS AND LESSONS LEARNED

Until now, even with the complexity of the student projects (e.g. drone system to design, build and operate), all the companies (combination of teams) successfully demonstrated the ability of their product by building a prototype of the designed product and performing the proposed missions to varying levels of success.

It is often reported that students from other introductory projects would prefer the Aerospace-Mechanical project. The multidisciplinary team integration and the proposed challenges are very attractive propositions to them.

3.1. Energy required for change

The multiple iterations of the project format were mainly driven by limited available resources for change. At first, a step by step approach seemed the best way to control the potential risks and added cost of exploring new pedagogical systems while controlling student uncertainties generated by a never before experienced learning environment. Over time these small steps improved the situation but it was found the basic administrative course management system hindered the possible positive benefits of more integration.

The last iteration (Generation 4) represents a massive time investment in reorganizing all elements in the course: creating new content, adapting existing course management software, reorganizing team management and reviewing assessment systems.

3.2. Assessments

Assessment systems play a big role in the perception of authenticity of the project for the students. Students have become experts at identifying what "counts" for their grade

and what does not. In the context of professional practice this division does not exist, making the project work and documenting it are the main objectives.

To this end, based on the Conseil Supérieur de l'Éducation's analysis [2] rubrics based grids for the evaluation of reports made the objectives very clear to all, students and teaching staff. The report rating rubrics include technical writing elements and technical content elements, some identified to specific CEAB attributes. Each of the typically 20 items in the grid are described in a short paragraph of expected actionable content on a 4 level scale (above expected, expected, close to expected and below expected).

The descriptive nature of the expected levels based on industry practice generate very specific discussions on professional practice and technical communication. Assessment suddenly became a very clear form of feedback where teams started to express their disagreement with the evaluations and negotiated with the teaching staff their perceived level according to the criteria given. Report assessment became an opportunity for professional discussions instead of simply grade haggling.

3.3. Time for projects

Project course load remains an important issue. A conscious effort must be applied by the teaching staff not to increase course load. Behind the goal to create a very motivating challenge and project experience, always hides the risk of excessive complexity and workload. By asking students to keep detailed records of worktime for project management tasks, it becomes a very useful tool to properly adjust the project challenges.

Not giving sufficient time to work on challenges is an important source of frustration for students. With proper very structured review of time requirements by the teaching staff most issues can be managed beforehand. Flexibility in the expected outcomes must also be planned for in-situ situations that can always happen in projects.

3.4. Course systems

Project integration and student team integration is a very complex issue. Without a reviewed course management system, the academic barriers can affect negatively the project process to a point where authenticity is lost. To prevent this a detailed semester scenario must be planned where all course management issues are solved before the start. Among known issues: team selection, learning management system modifications, grade reporting, evaluation tools, course content, room reservations and online communication systems.

3.5. Mentor-student interactions

Student-mentor feedback is one of the most frequent positive comments from student project course reviews. The one on one interactions; discussing technical or team

issues is very important to students. It is a very rare occasion for large groups to interact closely with the teaching staff. Students greatly value this opportunity and request more occasions to interact.

From this need, a change in the oral presentation format at reviews is implemented. Oral presentations are regularly performed to develop student's communication skills. Following the evolution of this course, these oral presentations are now realigned as "Project Reviews". During their Project Review, teams are now challenged by the teaching staff acting as Design Manager and Vice-President. This creates a completely different dynamic, more interactive, going to the point, forcing speakers to adapt according to "Management" interests and agenda. At first this creates frustration for students not able to deliver their "well-prepared" presentation. But eventually, they better understand how to behave and adapt in such situations which are representative of the Project Review sessions regularly performed in the Aerospace industry.

4. CONCLUSION

This project approach provides first year engineering students with a large and authentic engineering work scope. Based on the CDIO perspective, this better develops needed engineer behaviors and competencies, motivates students and creates an eagerness to better understand subjects in their following courses.

Some of the students who graduated were hired by local aerospace industry. Their personal feedbacks along with the feedbacks of their industry supervisors confirm the real impact of this course and other project courses on their engineering education and engineering practice in industry.

Following the evolution of this course, other first year project courses are planning to realign their content. Considering the positive results obtained, we continue our efforts in this project course and share these results in order to improve engineering programs throughout the engineering education community.

Acknowledgements

Without the time, engagement, and total commitment of all members of the teaching staff: Alain Gaudet, eng. Pierre Gaudet, eng. and Patrice Rémy, eng. with a combined 150 years of engineering experience, and the initial and significant support of Guy Cloutier, eng. this continuous improvement process applied to the introductory aerospace project course would not be possible.

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