IMPLEMENTING PROJECT-BASED, "HANDS-ON", AND EXPERIENTIAL LEARNING IN THE AEROSPACE ENGINEERING PROGRAM AT CONCORDIA UNIVERSITY

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Abstract Experiential learning can be defined as “learning from experience or learning by doing” [1]. The effectiveness of the experiential learning technique depends on both the design and the implementation of the experience. The learning experience must be carefully designed so that students do not learn by rote but rather are obliged to self-teach, discover, and use engineering judgement to arrive at conclusions. Student interest and their perception of the project as being authentic is important for engagement. In this paper, the authors discuss the development and implementation of experiential and project-based learning in the new undergraduate aerospace engineering program at Concordia University. The paper describes a unique series of experiential learning experiences that have been implemented in the first, third, and final years of the program. Two of the authors are former aerospace industry design engineers, and a unique feature of the program is a blend of field-based experience and classroom-based learning made possible by collaborations with industrial partners and organizations external to the university.

Keywords: experiential learning, project-based learning, institutional collaboration, multi-disciplinary, hands-on laboratory, design engineering, aerospace design education.

1. INTRODUCTION

1.1. Experiential Learning

Experiential learning methods are an attempt to move away from the traditional form of classroom lecture, towards teaching methods where students both gain and apply knowledge to experience, while developing skills through new ways of learning [1] [2].

Experiential learning can be implemented as part of a project-based learning module, or as a stand-alone experience. Although a laboratory offered as part of a theoretical or engineering science course is sometimes seen as an example of an experiential learning scenario, the understanding and definition of experiential learning has evolved to include notions such as the proper balance between experiential activities and underlying theory, self-teaching, self-discovery, working in complex systems, reflection, emotional investment, accountability and the ability to work outside a perceived comfort zone [3]. Cantor [4] points out that experiential learning can help students by providing them with the necessary skills to transition into the workforce.

One of the desired outcomes of the experiential learning method is for the students to develop skills such as the willingness to alter their conception of a topic or idea, the ability to successfully communicate their position, self-management skills, the ability to work successfully both alone and in a group, and understanding how to be productive when working with people with views different from their own [5]. Schwartz [2] divides experiential learning into two broad categories: field-based experiences and classroom-based learning. Field-based learning includes internships and co-ops, while classroom-based learning includes group projects, simulations, presentations, and case-studies.

The effectiveness of the experiential learning techniques depends on both the design and the implementation of the experience. The learning experience must be carefully designed so that students do not learn by rote, but are rather obliged to self-teach, discover, and use engineering judgement to arrive at conclusions. Student interest and their perception of the project as being authentic is important for engagement. In this paper, the authors discuss the development and implementation of experiential and project-based learning in the new undergraduate aerospace engineering program at Concordia University. The paper describes experiential learning-based courses that have been implemented in the second, third and fourth years of the program. Two of the
authors are former aerospace design engineers, and as such, provide a unique blend of field-based experience and classroom-based learning made possible by collaborations with industrial partners and organizations external to the university.

1.2. Engineering Design

In the United States, the Accreditation Board for Engineering and Technology defines engineering design as: “Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.” [6].

Engineers Australia describes engineering design as: “The subject of 'Engineering' can be divided into two activities of analysis and synthesis. Analysis (research) is really Science or the study of materials, actions and life to better understand our world. We can call it 'Engineering Science' if the study focuses on materials, processes and material actions. However, when we start taking this knowledge and applying it to improve the quality of life, we are synthesizing knowledge. We are now being creative with our knowledge. This is DESIGN and is FUNDAMENTAL to ENGINEERING. ENGINEERING is DESIGN. Research and analysis is Science. Both Engineering and Science are important; but knowledge alone is of no consequence to the future of life if it does not manifest itself into material significance through DESIGN” [7].

The teaching of engineering design requires careful attention to the integration of engineering sciences, the knowledge of design processes, and the personal and professional skills necessary to take those engineering sciences and synthesize them to create the products that define and enhance our quality of life.

1.3. Aerospace Engineering Education

There exists a well-documented disconnect between the needs of the aerospace industry and the training of undergraduate engineers at the university level [8] [9] [10]. This gap is not unique to the aerospace industry [11] [12] [13], or to the North American context [14], but is of notable concern to the aerospace community in the Montreal area. Canada’s aerospace industry, when compared to other OECD countries, ranks first in productivity and strategic importance over total manufacturing, third in terms of R&D intensity and fifth in terms of GDP and revenues [15]. Along with Seattle and Toulouse, the Greater Montreal region is home to one of the world's leading aerospace hubs and has the second-largest density of aerospace jobs in the world [16]. Although the region boasts 4 undergraduate engineering programs, major aerospace firms regularly forego hiring local engineering graduates in favour of experienced design engineers from other countries because they feel our graduating engineers do not possess the skill sets they are seeking. As Concordia University is located at the heart of Montreal's aerospace community, this problem is directly relevant to its aerospace engineering program.

A high level of agreement exists within the aerospace community surrounding the core competencies and skills that should be acquired during an undergraduate engineering education, in that design engineers should possess the desired balance between both practice and theory, and both personal and interpersonal professional skills [17] [18]. Institutions across North America have taken several approaches to solving this problem; many of them centered on the final year Capstone Design Project and industry collaboration [19] [20] [21] [22] [23]. Despite several outstanding programs at well-known institutions [15] [20] [19], the dissatisfaction felt by industry with the design engineering content of our undergraduate engineering programs is still evident. The outcomes of the undergraduate aerospace engineering program at Concordia University are expected to contribute directly to solving this problem through changes to curriculum, teaching and learning strategies, assessment, research, evaluation and continuous improvement.

1.4. Complexity in Aerospace Design Problems

There is a significant difference between simple and complex design problems. Teaching students using simple problems, where input and output variables are directly related, does not adequately prepare them for the complexity of many real-life engineering problems. Aerospace design is an extremely complex, multidisciplinary, system-of-systems design problem, and provides a perfect example of the potential complexity of the challenges faced by engineers in the design engineering community.

The complexity of the engineering design problem can be expressed through the theory of parametric design. The structure of the parameter design problem assumes a set of input parameters that are used to create and modify a set of output parameters related to the function and performance of the design product. An uncoupled design problem is characterized by a one-to-one mapping of inputs and outputs, and the complexity of coupled design problems can be quantified by the number of variables and the degree of coupling associated with the structure, or mapping of the problem’s inputs and outputs [24]. The complexity of many real-life design problems has led to the development of techniques, including matrix mapping functional requirements to design parameters [25], and design structure matrices [26] [27]. These methodologies are useful principally because they expose the coupling amongst design tasks and allow the associated difficulties to be addressed directly. The aerospace design problem can be seen in this context as extremely complex and difficult to solve. Hirschi and Frey [24] point out that an important
The limited classroom space is at a premium, with classes and exams scheduled in evenings and on weekends in an attempt to optimize within the urban reality and maximize the use of the limited space available.

Students cannot be expected to learn to deal with complex engineering design challenges by performing simple problems where the parameters are not coupled. The ability to solve complex design problems is associated with experience and familiarity with the product structure, technical realities and constraints associated with the reference product domain [24], and that such a familiarity can vastly improve the success of a design. This supports the educational principle that exposing engineering students to a coherent sequence of hands-on and experiential learning throughout their undergraduate career will dramatically increase their ability to perform when exposed to a complex capstone scenario. Culver [28] makes the point that engineering students should be better prepared for the capstone experience through courses developed specifically to prepare them for a design experience, and Koen [29] and Atmana et al. [30] suggests that a series of design problems of increasing complexity should precede the capstone experience. Evans [31] suggests that, because of the steep learning curve, the final year of the undergraduate degree may not be the appropriate place for the capstone project.

1.5. Challenges in Engineering Design Education

Dutson et al. [32] note that, while there has been a proliferation of capstone course offerings in response to ABET requirements in the United States (equivalent to the CEAB in Canada), the success of the capstone implementation depends on multiple factors. The factors considered in their study include course format, course duration, student evaluation, faculty interest, faculty experience in design, faculty responsibility, project sources, project cost, industrial involvement, capstone team composition, and team size.

In addition to the challenges described by Dutson et al., in their discussion of capstone projects, a less-documented problem associated with experiential learning is space. The allocation of physical space is an important challenge associated with urban universities. The experiential learning experience can be restricted by lack of space for laboratories that require large pieces of equipment, and projects that require the construction of large-scale prototypes. Concordia is such a university, located in the heart of the downtown area in a city of approximately 1.7 million people [33]. At Concordia, even office and classroom space is at a premium, with classes and exams scheduled in evenings and on weekends in an attempt to optimize within the urban reality and maximize the use of the limited space available.

2. AEROSPACE ENGINEERING AT CONCORDIA UNIVERSITY

Concordia University introduced an undergraduate program in aerospace engineering in the Fall of 2016. As part of this new program, the Faculty of Engineering and Computer Science is addressing several of the challenges outlined by Dutson et al. in their review of the capstone literature [32]. The new program introduces a series of aerospace design courses to be taken in the first, third, and final years of the aerospace undergraduate curriculum [34]. The intent of the three courses is to introduce the students to the aerospace design process through a series of coherent design classes of increasing process and product complexity.

Students begin their studies with AERO 201, Introduction to Flight and Aerospace Systems. This course is designed to introduce them to the basic concepts of aerospace design through the analysis of mission capability, form, function, and regulatory requirements. In this course, students learn to recognize the geometrical features of various aircraft in relation to the function that the aircraft is expected to perform, they learn to appreciate the complexity and multi-disciplinary nature of the aerospace product, and experience first-hand the real-life integrated aircraft systems through a series of hands-on laboratories. The laboratories are offered in collaboration with a local aircraft technical training facility, the École nationale d’aérotechnique (l’ÉNA), in St-Hubert, Quebec. L’ÉNA is a specialized facility at the St-Hubert airport that includes 5 hangars, 30 airplanes and helicopters, systems test benches, structural laboratories, and a turbine engine test cell. A view of the main hangar at l’ÉNA can be seen in Figure 1.

Fig. 1. CÉGEP Edouard Mont-Petit aircraft technical training facility (ÉNA)
The students complete five laboratories at l’ÉNA during a semester, and each four-hour-long lab is entirely devoted to hands-on learning. The labs are broken down under the following headings:

a) Powertrain: students spend half of the 4-hour lab disassembling and inspecting a Pratt & Whitney PT6 engine, and the remaining half of the lab running another PT6 from the control room of an engine test cell

b) Structures: students learn and apply sheet-metal bending and riveting techniques by manufacturing a small sample of an aircraft structure

c) Avionics and Flight Controls: students sit in the cockpits of several different aircraft to maneuver mechanically, hydraulically, and electrically-powered systems as shown in Figure 2, explore avionics bays, and familiarize themselves with physical aircraft and aircraft systems.

d) Hydraulics and Helicopter Landing Gear: in the first half of the lab, students learn about hydraulic systems by creating circuits on a hydraulic test bench, as shown in Figure 3. The second half is dedicated to changing a helicopter landing gear from skids to floats, and covers everything from operating the overhead crane to removing and installing the landing gear fasteners.

e) Aerodynamics: the students learn both the theory behind and operation of wind-tunnel testing. The students conduct a series of experiments on two wind tunnels, one containing an airfoil, and the other containing a propeller.

In addition to the laboratories, the lecture portion of course covers the broader scope of aviation to introduce the students to the aerospace industry. A series of assignments has the students choose their favourite aircraft, and collect useful information on that aircraft throughout the semester.

The resulting data is collected and discussed in class regularly, to expose the students to an overview of current and historical aircraft specifications. Contextualizing specifications such as range, speed, altitude, and outer dimensions with examples of real aircraft introduces the students to thinking critically about the link between performance and design.

AERO 201 is the prerequisite for the third-year course, AERO 390: Aerospace Engineering Design Project. In this course, the students are required to participate in a design project in small sub-system groups of 4-5 students. However, all groups need to interact to develop one complete system, such as the elevator or rudder control system as shown in Figure 4. Examples of the sub-system divisions are demonstrated in Figure 4, and can include the actuation subsystem, the mechanical control from the cockpit to the actuator, the structural integration, the aerodynamic loads, etc.
This project aims to give the students a sense of the real design process they will be faced with in the aerospace industry. The instructional portion of the course includes an introduction to systems engineering, risk analysis, requirements management for complex systems, failure modes and certification constraints, using internationally recognized documentation such as the SAE ARP4754-A and SAE ARP4761. The project portion of the course requires the students to design and validate an aircraft control system, for a full-size aircraft, available at the Laboratoire d’enseignement des systèmes intégrés du Québec (LÉSIAQ). The system performance requirements for the control system design are based on an actual aircraft, but are provided to the students intentionally incomplete and in a generic format. This allows the students an opportunity to think critically about the required inputs for the design of the sub-system. The validation process requires the students to develop and implement their own experiment at the LÉSIAQ facility to justify their design. This design of experiments exercise followed by reporting on experimental and theoretical findings is meant to introduce the students to the design and testing phases of real-world aircraft development. Students partake in regular design reviews with the course professor throughout the semester, and present their final design and validation work at a final design review to a panel of aerospace industry subject matter experts.

The LÉSIAQ facility is dedicated to teaching aerospace technologies on a full-scale platform, and is a 10,000-square-foot laboratory equipped with a genuine integrated test bed (Iron Bird) for a Bombardier Challenger 300 business aircraft. It is, in effect, an airplane without the fuselage, and containing all the aircraft’s on-boards mechanical, hydraulic, electric and electronic systems. Two sections of the LÉSIAQ facility are shown; Figure 5 shows a birds-eye view of the tail of the iron bird, and Figure 6 demonstrates the cockpit, where students can input commands through the aircraft control systems while monitoring the effects using cameras and virtual replications of the aircraft systems.

Students experience several unique learning outcomes in this course. For one, performing tests at the LÉSIAQ facility allows the students to discover and reflect on the disconnect between their design and the real system. Students are also exposed to important details regarding system components and installation. Elements such as the mounting points of the rudder, and the placement of mechanical cables and pulleys, unveils the opportunity for a deeper level of understanding of aircraft function through real-life context.

AERO 390 is a prerequisite for AERO 490: Final Year Aircraft Design Project. In this capstone course, students are required to form an aircraft company and design an full-size aircraft to a set of requirements that mirrors a realistic request for proposals from a governmental or other procurement organization. A CAD depiction of the students’ work in response to the Canadian government’s RFP for the country’s next fixed wing search and rescue (FWSAR) aircraft is shown in Figure 7. Samples of the type of work accomplished during the course are presented in Figure 8, depicting the structural layout for the same airplane, and Figure 9, the systems layout for simulation and validation.

![Fig. 5. LÉSIAQ facility and the iron bird.](image)

![Fig. 6. LÉSIAQ facility cockpit.](image)

![Fig. 7. Canada’s next FWSAR aircraft from the AERO 490 2016/17 cohort.](image)
The AERO 490 capstone differs from traditional capstone courses in several ways. The course is mandatory for students enrolled on the aerospace program, but is open to any student from any engineering discipline. Additionally, the capstone group is open to up to 40 students. In the first two years of the program, the enrollment has been 32 students, all of whom must work as a single capstone design group. During the first two years of the program aerospace students have been a minority, but assume leadership roles as a result of their experience and training in the aerospace program. Another difference between the AERO 490 and traditional capstone projects is that the requirement to build and test the product, in this case, a full-size aircraft, is not feasible. Alternatively, the students are required to produce a conceptual design at the end of the first semester and to validate the assumptions they made during the second semester, where validation optionally take the form of detail design, simulation, and test. Students use software and hardware to do wind tunnel testing, electrical and hydraulic systems simulation for component sizing, full-size aircraft simulation for flight testing and validation of critical performance and handling characteristics, and human factors in design. During the second semester of the course, students are encouraged to follow the interests they have acquired in the first semester, as some students prefer building and testing while others prefer simulation and analysis. Regardless of their individual preferences, all participants find themselves required to interact with each other as a direct consequence of the complex nature of the coupled parameter system that is characteristic of a complex design problem.

Each student is supported and held accountable throughout the semester via weekly design reviews, whereby a student can choose to present their work to the “chief designer”, being the professor, and regular guests from the aerospace industry. The students have upwards of thirty opportunities to practice presenting highly technical work to varying audiences, including their peers, and are exposed to the type of constructive critique they can expect to receive at design reviews in an industry setting. The students also organize their own mid-year and final design reviews, where they are asked to prepare everything from invitations to room bookings, and present their cumulative work to upwards of 60 guests comprised of faculty, staff, students, and industry subject matter experts. In addition to technical skills, professional skills such as conflict resolution, communication, time and personnel management, and confidence in technical writing and presentations are a few of the professional competencies that students develop over the course. The students are also given access to a design space, equipped with capable computers, relevant and up-to-date software, mobile tables, white-boards, and a library of foundational aircraft design textbooks. The welcoming and accessible space creates an environment that fosters collaboration, and helps to develop a strong sense of comradery both among the students, and between the students and the supporting faculty and staff that also share the workspace.

3. CONCLUSIONS

Concordia University has implemented a new undergraduate program in aerospace engineering. In doing so, the university has endeavored to overcome some of the obstacles identified as challenges to the successful implementation of project-based learning in general and in capstone courses. Issues related to course format and faculty experience in design have been addressed by the targeted hiring of faculty with rich experience in aerospace design engineering. Concerns about faculty interest and availability are directly targeted through the NSERC Chairs in Design Engineering program by offering full two-semester teaching credit for the faculty member responsible for supervising the capstone group. Project sources have been enriched by the participation of industrial partners from the aerospace community who participate in developing the capstone project description and participate in design reviews and mentoring with the students. Students are prepared for the capstone experience through a coherent series of design-related courses and project cost is minimized through collaborations with other institutions for the sharing of resources in an urban environment where space is a limiting factor for experiential course design.
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