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Comparison and analysis of leadership and management competences in first year engineering design courses.

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CONTEXT
The increasingly complex nature of societal sustainability and related technical challenges requires engineers to develop, deliver, communicate, and steward effective engineering solutions. The development of leadership and management competences in engineering students is key to building their capacity to work in this context now and in the future. In contrast to math and engineering science, which is carefully scaffolded in the curriculum, non-technical core competences are often left as 'experiential components' in team based design courses, work integrated learning or co-curricular activities. There is a need for engineering educators to have tools and frameworks that can be used to design, plan, assess and compare learning activities that support the progressive development of professional and contextual skills in the engineering curriculum.

PURPOSE OR GOAL
This study describes the application of a leadership management development model (LMDM) as a content analysis tool to assess the intentional development of leadership and management competences in the engineering curriculum, specifically in first year design. An analysis methodology is developed, and through the application of the original framework, an updated version was constructed. Engineering educators can use the framework to quantify and assess leadership and management learning activities as they are developed through the curriculum.

APPROACH OR METHODOLOGY/METHODS
The authors have developed an LMDM (Jamieson & Donald, 2020) based on a domain of influence leadership model and a transformational model of management functions. These models were utilized in the analysis of two large first year engineering design courses at two universities. Course activities were described, mapped to leadership and management frameworks, and categorized according to the engineering graduate attributes as defined by the national engineering accreditation body. The syllabi were compared and analysed on many aspects (e.g., self-leadership, societal impacts, relationship management) with a series of comparative charts and tables.

ACTUAL OR ANTICIPATED OUTCOMES
An analysis process and taxonomy is developed to assess and compare the learning activities of the two courses with respect to the development of leadership and management knowledge and skills. As a result of the mapping, process improvements were made to the LMDM. This information provides relevant insights both within and between programs that can act as an evidenced-based frame for improving the courses with respect to leadership and management development content.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Preliminary results indicate the model is effective at capturing and comparing engineering leadership and management functional coverage in the engineering curriculum. Ultimately the authors hope the framework can help engineering programs develop, plan, and assess undergraduate professional and contextual skill development in learning activities and the curriculum. We hope to support the development of non-technical engineering skills at the same level and rigour as technical skills.

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KEYWORDS

Engineering Leadership, Engineering Design, First Year

Introduction

Identifying engineering leadership and management activities and skill development in the curriculum can be challenging. In this work we examine the utility of a leadership and management development model (LMDM) framework, developed by the authors, to enhance the understanding of leadership and management skills in the engineering curriculum. Using the LMDM and the Canadian Engineering Accreditation Board (CEAB) Graduate Attribute (GA) frameworks we analyze and compare the content of the first-year undergraduate engineering design courses at two different Canadian universities: the University of Alberta (UofA) and the University of Guelph (UofG). Each course is common to all first-year students and provides an introduction to engineering and design.

In addition to demonstrating the utility of the LMDM framework as an effective tool for gaining insights related to leadership and management competencies in the first-year courses, the purpose of this study is to provide an initial benchmark for course improvement and further development work. The LMDM can provide an evidence-based understanding of the extent of exposure in the two courses to leadership and management competencies critical to the sustainability mindset. The resulting analysis is useful in articulating the relevance of learning in the context of engineering practice.

Background

The CEAB GA are based on the International Engineering Alliance (IEA) Washington Accord graduate attributes. These GA are briefly presented in Appendix A and capture the outcomes of leadership (GA6) and project management (GA11). Beyond the limited description provided in the CEAB GA, instructors have little guidance to develop leadership and management curriculum to prepare content, learning activities, or students for the transition to future engineering practice. Faculty with industrial practice experience may rely on their own engineering leadership and management experiences, however the GA don’t offer a connection to an engineering leadership and management framework or to the cross disciplinary interactions found in practice. A framework connected to the GA outcomes is required for relevant course and program content analysis and development.

Targeting the development of a sustainable engineering mindset in students alongside the technical competencies, a leadership and management development model (LMDM) was proposed in previous work (M. Jamieson & Donald, 2020) as an engineering leadership and management competency framework for course and program development. The framework utilizes a leadership domain model with expanding levels of influence from self to team to organization to society. The non-technical skills captured in the CEAB GAs, such as GA 7-Communication, are required across all the leadership domains of influence. The management model originally proposed to support the LMDM structure was Birkinshaw’s management model framework (Birkinshaw, 2010), which addresses the organizational continuum from bureaucratic to emergent and identifies management functions that are relevant in the context of addressing increased corporate responsibility with growth targeted to sustainable development; namely, managing across, managing down, managing by objectives, and managing motivation.

Both of the first-year design courses examined in this study include students from all the engineering programs offered at the institution. At the UofA, all students are admitted to first year engineering and select their discipline after completing their first year. At the UofG, the majority of the students are admitted directly to their discipline. The UofG intentionally establishes teams composed of students from different program disciplines. As all UofA students are undeclared, students form teams based on project interest. At the UofA, the design course is intentionally transdisciplinary where all students examine societal problems through an engineering practice lens situated in a complex world. At the UofG the design course is intended to be an interdisciplinary build-design experience and the design process is also intentionally transdisciplinary. Definitions of transdisciplinary and interdisciplinary are provided in Appendix B.

Both courses introduce the students to professionalism and engineering ethics. Ethics is often under-represented in the engineering curriculum (Martin & Polmear, 2021) yet it is part of the professional skillset that overlaps the engineering leadership and management domains (M. Jamieson & Donald, 2020, p. 5). Engineering leadership, management, professionalism, and ethics are critical to sustainable development as engineers need to evaluate the technical options in the context of developing sustainable solutions and evaluating technical and nontechnical design criteria. Martin and Polmear (2021) also identify the shifting focus of the engineering curriculum towards the explicit inclusion of socio-technical and professional skills. In addition, they also identify challenges in transitioning from the historical technical focus to a more holistic engineering education.

Methodology

The two first-year design courses compared were ENGG 160 (UofA) and ENGG*1100 (UofG). The UofA course was redeveloped for the second time as a gamified course. The UofG course has been offered for over 5 years in its current form. Activities for the most recent course iterations were described, mapped to the LMDM framework, and categorized using the CEAB GA. A team of six researchers carried out the comparison, developed the LMDM management function adaptation, and finally the content analysis and comparison. Two of the researchers were the LMDM developers and course instructors. Engineering co-op students comprised the rest of the team. The UofG co-op students had taken the course as students. The UofA co-op students previously assisted with course gamification and implementation. All members of the analysis team were very familiar with one of the two courses and much less familiar with the other course. The learning outcomes (LO) from both courses were previously mapped to the CEAB GA. An analysis process was developed through joint consultation and the steps of the process are outlined as follows:

1. **Describe:** Describe each course so that teams become familiar with each course.
2. **Compare Courses:** Review descriptions and syllabi to analyze the course structure and learning objectives for the courses. Report structural similarities and differences.
3. **Map and Compare GA:** Map graduate attribute coverage in the course learning activities overall and on a weekly basis. Separate and analyze the content in the courses by the structural elements (e.g., lectures, projects, labs, assessments).
4. **Map and Compare Leadership Domains:** For the course overall and with respect to the course structural elements, analyze the learning activities and map to the LMDM leadership domain levels students are exposed to and/or required to practice in activities. Identify gaps for discussion and validation.
5. **Map and Compare Management Functions:** Repeat Step 4 for the LMDM management functions.
6. **Validate Content Analysis:** Teams review and cross check the other teams work related to the GA, leadership domain and management function mapping.

Steps 1 and 2 were completed by the whole team, steps 3, 4 and 5 were completed by the teams most familiar with the courses, and step 6 was completed by the whole team.

As the method for content analysis was being tested the team noted challenges mapping the LMDM management functions. The original LMDM framework considered multiple organizational engineering management levels and used Birkinshaw's model (2010). While this model is useful in the context of developing an engineering mindset to support transformational goals (e.g., sustainable development, diversity, culture change) it proved less useful for course and program content analysis. We found the management function language used in Birkinshaw’s continuum of traditional and alternative principles difficult to apply to learning activity analysis and classification. To complete the mapping of the course activities we felt that descriptors more aligned with project management were required.

Four commonly accepted functions of management are planning, organizing, leading and controlling (McDonald, 2010; Schraeder et al., 2014). Leadership as a management function in the LMDM would be confusing because leadership is contextualized as a full set of influence domains. We chose to replace leadership with directing. The original descriptors mapped to the new descriptors as follows: managing across - activities, plan; managing down - decisions, organize; managing objectives, control; and managing motivation, directing. A revision of the LMDM was constructed to include a general management function framework as shown in Figure 1. The management functions of plan, organize, direct, and control are well aligned with the original model, translate directly to engineering practice and are more easily applied to learning activity classification. Using this updated version of the LMDM engineering educators can use the framework to identify and assess leadership and management learning activity in individual courses and subsequently programs. The management functions were arranged in the order students would typically apply them in project development and management in our courses and represent increasing managerial task complexity and progression at the team and project level.

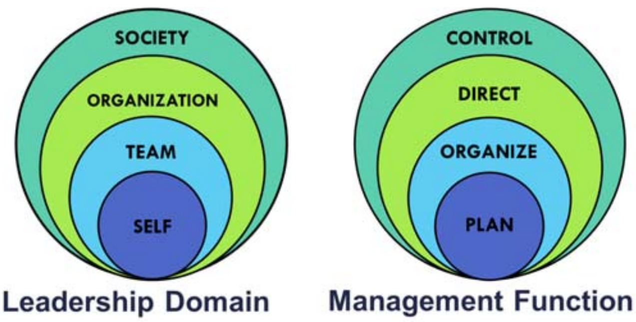

Figure 1 - Analysis Frameworks - Leadership Domains and Management Functions

Results

Course Description (Step 1) -The UofA first year design course (ENGG 160) has one in class synchronous lecture hour, one online asynchronous lecture hour, and one asynchronous online seminar hour per week. Enrolment is typically 1200 in three sections and the course is delivered in the second term of first year prior to selecting one of the 14 different engineering programs offered. ENGG 160 utilizes competency based grading in a gamified format and is offered as a credit/no credit course. Students complete the course activities and collect badges to pass the course and gain credit. Course activities, including a team design project, are aligned with five badge categories (sustainability, design, teamwork, safety, and learning). Learning activities consist of short video lectures, readings, quizzes, team and project based assignments including reflections and evaluations. A student must meet the requirements for all the badge categories by earning milestone badges leading to earning the category badge. Completion is achieved when all badges are collected. Students receive feedback on attempts and during project development so that students who do not meet competency targets may resubmit their work.

The UofG first year design course (ENGG*1100) delivery structure consists of 2 hours of in-class lectures, 2 hours of design lab/studio activity and 2 hours of computer lab activity. Enrolment is typically 400 and the course is delivered in the first semester to the entire first-year cohort comprising 7 different engineering programs. Lectures are delivered in one large section of 400 students, and the computer labs are typically sized at 50-60 students. The course is supported by additional video materials and formative practice modules. In the lectures, the engineering profession, the responsibilities of an engineer and the engineering design process is introduced. Students learn computer aided design in the computer labs and the design labs are utilized for the development and implementation of the major team project. Much of the computer lab and lecture material is integrated into the delivery of the major team project, and a variety of graded written assignments related to ethics, professionalism, sustainability, and design are also delivered.

Course Comparison (Step 2) - Both courses share many common learning outcomes as shown in Figure 2. A structural comparison of the two courses is presented in Table 1. A central component of each course is a semester-long team design project. The UofA focuses on a community design project in a transdisciplinary context (Jamieson et al., 2021) and the UofG focuses on the design of an autonomous model vehicle that must meet client specified functional, aesthetic and sustainable design requirements, as well as demonstrate performance in various challenge events (Stiver, 2015). The autonomous model vehicle is a "Teddy Bear Wheel Chair" (TBWC). Teams are composed of students from across all engineering programs with no specified discipline-specific responsibilities in the project.

Figure 2 - Comparison of learning outcomes and course themes for two courses

The UofA has a transdisciplinary team focus (Dykes et al., 2009) and the UofG has an interdisciplinary team focus. Both courses use a transdisciplinary design process. The UofA design process uses the following stages: Planning, Concept development, System level design, Detailed Design, Implementation and testing, and Production as developed in a collaborative research project where 71 professors across 8 disciplines provided input (Butt et al., 2018). During the last course iteration when sustainable development principles were incorporated into the course content an additional stage was added to the design process: Recycling and Reclamation to better connect the transdisciplinary design process to the circular economy, sustainability, and a circular flow of resources.

Table 1 - First-year course structural comparison

Course	**U of A ENGG 160**	**U of G ENGG*1100**
Main Project/ Prototype	Problem Framing and Conceptual Community Based Design Project Prototype Assignment	'Build-Design' Project (TBWC) Prototype Demonstration
Project	11 Progressive Assessments	8 Progressive Assessments
Format	Blended Lecture-Seminar	Face to Face Lecture-Lab
Weekly Hours	(3)	(6)
Team Size	6 to 7	4 to 5

The UofG project design process is presented in lectures and built into the scheduled team project deliverables. After prototyping and final design stage completion, students report on elements of the process and details of the design. Students learn requisite skills and the design process in parallel. For example, 3D CAD software is used to produce detailed drawings after the prototypes and final designs are complete and design elements such as safety calculations and life cycle analysis are completed for the final design. This "Build-Design" approach captures the iterative design process, versus a traditional design build.

<u>Map and Compare Graduate Attribute (Step 3)</u> - The GA distribution for both courses is shown in Figure 3. Both courses develop all 12 of the GAs (Figure 3a) and consistently progress GA development throughout a 12-week term (Figure 3b). The most frequent GA noted in both courses was GA 6 (individual and team work) consistent with students working in teams and reflecting on the team progress throughout the courses. For ENGG 160 the next most frequent was GA 7 (communication) and for ENGG*1100 it was GA 5 (engineering tools). For ENGG 160 this is explained by the progressive weekly project update assignments completed by the design team and handed in for feedback. For ENGG*1100, communication is also strongly represented as a result of additional sustainable design and innovation essay assignments. In ENGG*1100 there is a focus on competency development in engineering tools, particularly computer aided design and in prototype design and build. The engineering tools component is less prominent in ENG 160 as this aspect is included elsewhere in the program. In ENGG 160 societal impacts, professionalism, ethics, economics and sustainability (GA 8-11) are seen more frequently than in ENGG*1100 as students are engaged in the problem framing and sustainable conceptual design of the challenging community problem projects, and ENGG*1100 focus on the autonomous vehicle build-design.

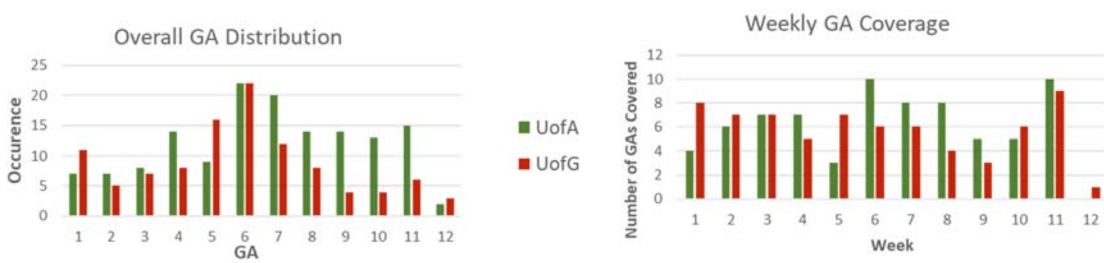

Figure 3 - Graduate Attribute Overall (3a) and Weekly (3b) Coverage Comparisons

<u>Map and Compare Leadership Domain and Management Function Content (Steps 4 & 5)</u> - The leadership domains and the management functions presented in Figure 1 were used to classify the learning activities and analyze the project schedules of the UofA and the UofG first year design courses. For example, an exercise related to self-reflection on personal contribution and performance would map to the "Self" leadership domain, and an activity related to developing a schedule of project activities would map into the "Plan" management function. The overall summary and comparison of the classification of learning activities with respect to the leadership domain distribution, and with respect to management functions are shown in Figure 4 and 5 respectively.

The course structural elements, namely, lectures, project work, and supporting content were further analyzed and the resultant lecture and project activity mapping are shown in Figure 6.

Lectures: The UofA lecture components focus on the transdisciplinary design process, professionalism, ethics and project management with a strong emphasis on society. The UofG lecture components emphasize team and self-leadership. The lectures primarily focus on team development topics and with a balanced approach to the remaining domains of self, organization, and society.

Design Project: The UofA societal impact project is framed around a community need (e.g., housing, transit, energy) and the UN SDGs. Students consider stakeholder impact and sustainability. The UofG project, the design of a Teddy Bear Wheelchair, is product development focused on a specific client need balancing performance and sustainability.

Supporting Content: Supporting content was variable between the two courses and included activities such as computer labs, videos, readings and case studies. The distribution of the leadership and management function activities was similar between the two courses with differences noted between societal and self-leadership.

Validate Content Analysis (Step 6) - Weekly progress was discussed within the research team and comparisons of how activities were classified were reviewed. This step was crucial to our process and at times required review of activity classification and reclassifications for consistency.

Figure 4 - Leadership Domain Course Content - Overall

Figure 5 - Management Function Course Content - Overall

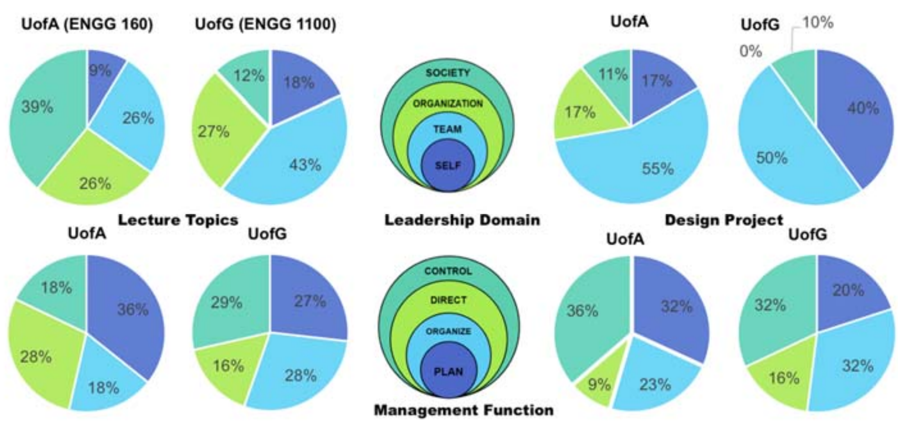

Figure 6 - LMDM Comparison - Lecture Content and Design Project

Discussion

As a result of the mapping process improvements were made to the LMDM by revising the management functions to plan, organize, direct, and control. Benchmarking the two first year courses using the modified LMDM provided a framework for course comparison with respect to leadership domains and management functions relevant to engineering practice and GA development. The analysis provided insight into both the design courses and the extent to which engineering leadership and management were incorporated. Both courses included learning activities across all management functions and leadership domains. It was found that each of the introductory design courses consistently capture all the GA both weekly and overall. The LMDM appears to be a useful method to connect engineering leadership domains and management functions to the GAs and to engineering practice. As the LMDM maps to all the GAs it would appear this method could be leveraged to assess other courses, especially design and practice based courses.

Beyond the lectures and the project, the supporting content had variable LMDM coverage. The UofA supporting content was set up to support the development of the project design and the stages of the design project process. The UofG supporting content addresses student development needs to better prepare them for using the engineering tools required for the programs. Although the focus is different, both institutions have addressed student preparedness and lay a foundation for engineering design, leadership, and management in the context of sustainability. We note community projects with a sustainability focus contributed significantly to the difference observed with respect to the societal and organizational leadership domains between the two courses.

Conclusions and Recommendations

The content analysis process development was a collaborative effort that yielded a comparison of the learning activities in the courses. The LMDM mapping comparisons can be used to reflect on the curricular content distribution. Based on the two courses analyzed, it appears that the design project topic may influence the leadership domains student activities encompass, and that the course project structure itself has more impact on the management functions. The management functions did not seem to be dependent on the project topic or phase of the design processes focussed on, however the leadership domains were focus dependent. The UofA focussed on problem framing and conceptual design where the UofG course provided a build design experience for students. Overall both courses gave students experience in all management functions, leadership domains, and graduate attributes.

Overall, the LMDM framework allowed us to effectively analyze the course content for leadership, management, and the connections to GA coverage. The LMDM allows for a structured approach to obtain a greater depth of understanding of the leadership and management competences than can be gathered using only GAs. This can aid in comparing non-technical content both within and across courses and programs. The use of the LMDM provides an initial benchmark that will inform course improvements for both course instructors and supports the goal of building a foundational engineering mindset in first year.

Preliminary results indicate the model is effective at capturing and comparing engineering leadership and management functional coverage in the engineering curriculum. We plan to apply the model to additional engineering courses to refine the LMDM itself and gain insight into the engineering curriculum from the leadership and management perspective. Ultimately the authors hope the framework can help engineering programs develop, plan, and assess undergraduate professional and contextual skill development in the curriculum at the same level and rigour as technical skills.

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Appendix A – CEAB Graduate Attribute List

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society and environment
10. Ethics and equity
11. Economics and project management
12. Life-long learning

CEAB. 2020 Accreditation Criteria and Procedures. Engineers Canada.

Appendix B – Definitions

Transdisciplinary: the intentional combination of individual expertise in one or more disciplines to create a new discipline and perspective for solving (design) problems.

Interdisciplinary: the intentional cooperation of individuals from different disciplines to solve a (design) problem by developing a shared understanding.

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