COMPARISON OF THE CIVIL ENGINEERING CURRICULUM AMONG SEVERAL CANADIAN UNIVERSITIES

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Abstract – Growing attention to environmental sustainability, modular construction, and application of new generation of materials, accompanied with advanced data collection techniques and computer modeling, has revolutionized the area of Civil Engineering within the past few years. This demonstrates the necessity of continually reviewing the curriculum to assure that graduating engineers are knowledgeable enough to deal with complex problems in their area of specialty. This is also essential to satisfy the continual improvement process (CIP) requirements mandated by the Canadian Engineering Accreditation Board (CEAB). As a first step to design a rigorous CIP, a comprehensive comparison was made between the Civil Engineering curricula of the University of Alberta (UofA) and eight other major universities across Canada, including the University of Calgary, University of Toronto, McGill University, University of Windsor, University of Regina, University of British Columbia (UBC), University of Waterloo, and Polytechnic of Montreal. After categorizing the courses into twelve different streams, it was observed that some universities paid less attention to a specific stream in comparison with the average, which could be identified as a gap in the curriculum. A capstone design or group design project that is multidisciplinary and covers multiple areas of specialty is the predominant approach followed by most of the universities.

Keywords: Canadian Universities, Comparison, Civil Engineering, Curriculum, CIP, CEAB

1. INTRODUCTION

According to the American Society of Civil Engineers (ASCE), civil engineering is defined as a profession in which applying the knowledge of mathematics and physics obtained through study, practice and experience, accompanied with engineering judgement, makes it possible for professionals to preserve the environment and build facilities and transportation systems [1,2]. The Canadian Engineering Accreditation Board (CEAB), a committee of Engineers Canada, was established in 1965 to assure that Canadian undergraduate programs satisfy the educational criteria for professional engineering registration in Canada by establishing the required content of various engineering programs, including Civil

Engineering, in a general way [3]. The nature of its generality provides enough flexibility to include innovations, regional parameters, and universities' specific qualities, as well as educational goals. This also explains why academic programs including civil engineering vary among different universities in Canada but can still meet the criteria set by the accreditation board [4]. However, to harmonize the exam syllabus for people who did not graduate from an accredited Canadian engineering program and who would like to be a licenced engineer, there is a published list of examination syllabus (courses) in the Civil Engineering discipline and other areas of Engineering. This list is reflective of required courses that need to be included in the curriculum of each university [5]. Furthermore, the CEAB mandates each engineering program in Canada must assess the outcomes of their graduates in the form of twelve attributes and use these results to continually improve the program [3].

The goal of the research reported here is to compare the Civil Engineering curricula among different Canadian Universities to provide a resource and better understanding to institutes and colleagues ameliorating their performance through a comprehensive improvement process.

2. METHODOLOGY

A comprehensive comparison was made between the curricula of nine major universities across Canada including the University of Alberta (UofA), University of Calgary, University of Toronto, McGill University, University of Windsor, University of Regina, University of British Columbia (UBC), University of Waterloo, and Polytechnic of Montreal. Data were collected from the online curriculum of each program in December 2019. It should be noted that the outcome of this research is based on the available data and may not be applicable if the curriculum of a university changes for upcoming semesters. To make it possible to compare, twelve different streams including graphics and computing, surveying, chemistry and materials, mechanics and structural analysis, math and its application, construction engineering, geotechnical engineering, transportation, structural design, environmental engineering, water resources engineering, and general design were defined based on the prerequisite of different topics. The six streams that include construction engineering, geotechnical engineering,

transportation, structural design, environmental engineering and water resources are categorized as the technical areas appropriate to civil engineering according to [1] and will be termed the “sub-discipline streams”. General design stream covers courses with design content that were titled as capstone design or group design project in the majority of the universities. The frequency of each stream was calculated as the ratio of the total number of courses at each stream to the total number of courses at all streams, presented as percentage. In counting the number of courses, no difference was made between the core and elective ones. Co-op components in the curricula were not the focus of this paper.

3. RESULTS AND DISCUSSION

This section describes the result of the analysis performed on the streams extracted from the curricula of studied universities. First, a brief description of the various Civil Engineering programs and the distribution of different streams within their curriculum is explained. Fig. 1 shows the distribution of various streams between centres. Later, a comparison of streams between centres, elective, and design courses, as well as limitations of this study, are discussed.

3.1. Summary of each program

3.1.1. UofA. The traditional Civil Engineering program at the UofA is four years, consisting of eight semesters. Only one course is offered during the spring/summer semester (survey school, a one week course). A total of 42 courses are offered among all streams, 12 of which are design courses provided as technical electives. All design courses are specialized to one of the six sub-discipline streams of construction, geotechnical, transportation, structural design, environmental and water resources engineering. Students take five out of these 12 elective design courses. Among different streams, math and its application has the maximum frequency of 19%, whereas surveying and graphics has the minimum frequency at the UofA of 5%. A frequency of 12% is observed for mechanics and structural analysis. Chemistry and materials, water resources, geotechnical engineering, and environmental engineering all have frequencies of 10%. Structural design, transportation, and construction engineering attain frequencies of 7%.

3.1.2. University of Calgary. The four-year Civil Engineering program (eight semesters) at the University of Calgary includes 33 courses distributed among the twelve mentioned streams. No surveying course was offered in this program at the time of data collection. Students are required to take one compulsory design course during their fourth year, namely a group design project that covers all the aforementioned sub-discipline streams covered at the UofA. Eight courses can be taken from a list of nine

technical electives in all streams. At the University of Calgary, water resources, graphics and computing, and construction engineering each have a frequency of 6%. Math and its application, as well as mechanics and structural analysis streams, have frequencies of 18 and 15%, respectively. The remaining streams (except surveying) attain frequencies of 9%.

3.1.3. University of Windsor. In total, 39 courses are offered at this university through all streams. Capstone design is offered during the fourth year as a two-semester compulsory course. One elective course can be taken from one of the geotechnical, structural design, transportation engineering, environmental, or water resources streams. Among all streams, math and its application has the maximum frequency of 18%, which is 3% higher than mechanics and structural analysis (15%). Surveying, graphics and computing, as well as construction engineering, attained frequencies of 3%. Water resources, structural design, and geotechnical engineering streams have frequencies of 10%, whereas frequencies of 8% are noted for the environmental engineering, transportation, and chemistry and materials streams.

3.1.4. University of Regina. A total of 39 courses are offered at the University of Regina throughout the whole program, and students are allowed to take five courses out of eight electives. Two courses related to general design stream (i.e EVSE Project Start-up and Environmental Systems Engineering Design Project and Communications) are offered in the last year. At the University of Regina, water resources stream has the highest frequency of 21%. Environmental engineering, as well as math and its application, are in the second rank with frequencies of 15%. Transportation, mechanical and structural analysis, as well as chemistry and materials, have frequencies of 8%. Surveying, graphics and computing and geotechnical engineering attain frequencies of 5%. Minimum frequencies of 3% are calculated for the structural design and construction streams.

3.1.5. University of Toronto. University of Toronto provides 59 courses in all streams over the fall and winter semesters, of which 28 are electives. Among electives, students are allowed to take only four courses. A compulsory group design project provided in their last semester, giving a frequency of 2%. At the University of Toronto, water resources and mechanics and structural analysis both have the same frequency values of 8%. Environmental engineering has the maximum frequency of 20%, while surveying has the minimum frequency of 2%. Structural design and math and its application both have frequencies of 10%. Transportation and construction engineering attain frequencies of 7%. Chemistry and materials, geotechnical engineering as well as graphics and computing have frequencies of 5, 17 and 3%, respectively.

3.1.6. University of McGill. The Civil Engineering program at the McGill University contains 58 courses distributed among the twelve streams. Of these, 31 courses are technical electives, and students are allowed to select five of them. One compulsory design project course is offered during their last semester. The prevalence of the environmental engineering stream (i.e. 17 %) is the highest among all streams. Water resources and math and its application with the prevalence of 16% and 14% are in the second and third rank, respectively. Structural design, transportation, mechanics and structural analysis, as well as chemistry and materials, all have frequencies of 9%. The minimum frequency is obtained for surveying and general design stream with 2%. The frequency of graphics and computing is slightly higher than surveying, reaching the prevalence of 3%. The frequencies of geotechnical and construction streams are 5 and 7%, respectively.

3.1.7. University of British Columbia. The four-year Civil Engineering program at the University of British Columbia consists of 63 courses, including 31 technical electives. Students are allowed to take 15 credits among those technical elective ones. Capstone design projects I and II are offered as compulsory courses in the last year of their program with the frequency of 3%. The minimum frequency is for surveying (2%), whereas the highest is for structural design stream, with the frequency of 17%, followed by environmental engineering (14%). The value is 13% for water resources stream and 11% for geotechnical, as well as math and its application. Four out of 63 courses (i.e. 6%) are assigned to construction, as well as chemistry and materials stream. This value is five for mechanics and structural analysis (8%), three for transportation (5%), and two for graphics and computing (3%).

3.1.8. University of Waterloo. The traditional Civil Engineering program at the University of Waterloo is four years, including 47 courses of all streams where 21 are combination of design technical electives and technical electives. Of those electives, eight should be taken over the last three semesters. No surveying course is offered in the program. It is required that students take two courses in general design stream (i.e. Civil Engineering design project I and II) during the last two consecutive semesters of their study. 17% of the streams are assigned to mechanics and structural analysis. This value is 15% for environmental engineering. Structural design as well as math and its application streams both have the frequency of 13%. Graphics and computing has the minimum frequency of 2% among all streams. The prevalence of construction, as well as chemistry and materials, is only 2% greater than graphics (i.e. 4%). The water resources, geotechnical engineering, and transportation streams have frequencies of 9, 9, and 11%, respectively.

3.1.9. Polytechnic of Montreal. Polytechnic of Montreal delivers 88 courses with 55 electives, covering all streams over the four-year traditional Civil Engineering program. To complete the program requirements, students should choose 12 credits from either the specialty or thematic orientations. The Civil Engineering design project is offered as a compulsory course over the last year in the general design stream. Among all streams, environmental engineering has the maximum frequency of 25%, whereas math and its application is in the second rank with the frequency of 20%. The minimum frequency of 1% is assigned to chemistry and materials. The frequency of surveying, as well as construction stream, is slightly greater than chemistry and its applications (i.e. 2%). Five out of 88 courses (6%) were assigned to transportation or to mechanics and structural analysis. Water resources and geotechnical engineering have almost the same frequency of 14%. The frequencies of structural design, as well as graphics and computing, are 7% and 3%, respectively.

3.2. Comparison of streams among universities

For comparison, the average of each stream among all universities was calculated. The universities with the highest frequencies along with those with a frequency of equal or less than 50% of the average were identified.

3.2.1. Water resources. The average of water resources stream among all universities is 12%. This stream has the highest frequency at the University of Regina with 21% and the lowest at the University of Calgary with 6%.

3.2.2. Environmental engineering. Polytechnic of Montreal has the highest frequency of 25% in environmental engineering. This value is 8% for the University of Windsor. Considering the average of 15% for this stream, the University of Windsor has the lowest frequency at about half of the average.

3.2.3. Structural design. 9% is the average for the structural design stream among all universities. UBC has the highest frequency of 17%, whereas Regina has the lowest at 3%.

3.2.4. Transportation. The average of transportation stream among various universities is 8%. All universities offered a sufficient amount of coursework in transportation engineering according to defined criteria. The maximum frequency of 11% is reported for the University of Waterloo.

3.2.5. Geotechnical engineering. The maximum frequency of 17% is observed for the geotechnical engineering at the University of Toronto. The minimum value of 5% is calculated for both McGill University and University of Regina. Compared to the average of 10%,

these two universities offer about 50% fewer courses in geotechnical engineering.

3.2.6. Construction engineering. The average of 5% is obtained for construction engineering stream among all universities. The minimum frequency of 2% is found for construction engineering at the Polytechnic of Montreal whereas the maximum value of 7% was calculated for the University of Toronto, McGill and UofA.

3.2.7. Math and its applications. The average frequency is 15%, and no university offers less than 50% of the average. The maximum frequency of 20% for math and its applications occurs at the University of Montreal. UofA with 19% is in the second rank. The minimum frequency of 10% is found for the University of Toronto.

3.2.8. Mechanics and structural analysis. The average frequency of is 11%, and no university offers less than 50% of the average. The maximum frequency of 17% for mechanics and structural analysis occurs at the University of Waterloo. The minimum frequency of 6% is found for the Polytechnic of Montreal.

3.2.9. Chemistry and materials. Given the average of 7% among all universities, minimum consideration of chemistry and materials is observed at the Polytechnic of Montreal with 1% frequency. The UofA, with a frequency of 10%, is ranked as the highest, followed by the University of Calgary with 9%.

3.2.10. Surveying. The average of this stream among all universities is 2%, with the highest frequency of 5% at the UofA and University of Regina. Surveying is not offered in the traditional Civil Engineering program at the University of Calgary and Waterloo. It is possible that these are offered as components of other courses, but this was out of the scope of this research.

3.2.11. Graphics and computing. The maximum frequency of 6% is found for graphics and computing at the University of Calgary. UofA and University of Regina with 5% frequency hold the second rank. Compared to the average frequency of 4%, no university offers less than half of the average.

3.2.12. General design. The average frequency of 3% is found for the general design stream among all universities. The minimum frequency of 1% is obtained for the Polytechnic of Montreal, whereas the maximum frequency of 5% is noted for the University of Windsor and Regina. It should be mentioned that the design courses at the UofA is considered in various sub-discipline streams.

Fig1. Distribution of streams among centers

3.3. Comparison of design and electives among different universities

Table 1 summarizes the number of courses defined in all streams, number of technical electives, and allowable technical electives offered by various centers. There is no consistency in total number of electives offered by various universities. The maximum number of offered technical electives is 55 courses, at the Polytechnic of Montreal. McGill, University of British Colombia, both with 31, and University of Toronto, with 28 electives, are in the second and third place. The lowest number of technical electives, 5 courses, is offered at the University of Windsor. Despite providing many options of technical elective courses, Polytechnic of Montreal allows the students to select only four of the 55. This might work as a double edge sword; such a high number of electives might be confusing for students to choose in an attempt to prepare themselves for future work. However, offering multiple courses with different topics in one area of specialty allows a graduate to be more specialized in one area. For example, one might select wood frame design, bridge design and design of multi-story (high-rise) buildings among all offered electives, allowing the student to be more specialized in structural design stream of Civil Engineering. Regarding project design courses (or capstone design projects), the review of the curricula of various universities reveals that UofA is the only university which provides the design course in the form of multiple elective design courses with final group projects. These design courses cover one of the six streams – construction, geotechnical, transportation, structural design, environmental, and water resources engineering. In other universities, general design stream is

offered over their last year and covers all mentioned streams at UofA.

Table 1: Summary of the number of courses defined in all streams, number of technical electives, and allowable technical electives

University	Total number of courses in all streams	Total number of technical electives in all streams	Number of allowable technical electives
Alberta	42	12	5
Calgary	33	9	8
Windsor	39	5	1
Regina	39	8	5
Toronto	59	28	4
McGill	58	31	5
UBC	63	31	5
Waterloo	47	21	8
Montreal	88	55	4

3.4. Overview of core and elective courses at each stream

Although the percentage-based comparison provides a comprehensive overview of the program relative to the total number of courses offered at each specific center, it might be misleading in some streams. Therefore, direct comparison of the number of core and elective courses is provided to give a more accurate overview of the streams covered by each university (Table 2). As an example, the construction engineering stream at the Polytechnic of Montreal has a minimum frequency of 2%, considering that 2 out of 88 courses offered at that University are in the construction engineering stream. This frequency is less than the average of 5% among all universities, which might be interpreted as the number of courses in the construction stream offered is less than for other universities. However, Table 2 indicates that Polytechnic of Montreal offers a sufficient number of courses relative to others.

There is a large discrepancy in the total number of courses offered for each stream. For example, the total number of core courses offered in geotechnical engineering for all universities is 22, whereas this value is 14 for the structural design stream. 26 and 31 are the total number of elective courses offered in the aforementioned streams, respectively. Among all streams, the maximum number of courses in total (i.e. 76) is assigned to environmental engineering. This is in line with the new vision for civil engineers in 2025, formulated by ASCE Task Committee, which requires more attention to the sustainability and environmental protection by Civil Engineers [1].

No consistency in the number of core and elective courses offered for each stream was observed among the universities. For example, the distribution of structural

design courses among universities varies between zero to three for core courses and between one to nine for electives. As it is seen in Table 2, fewer variations exist in the number of core courses offered in each stream among universities, when compared to electives. For example, for the water resources stream, the University of Windsor offers three core courses accompanied by one course as an elective. However, these values are two core and seven elective courses at McGill University. These variations can be explained by the fact that each university has its own background, qualities, and regional parameters that affect the number of courses offered. No core course in structural design stream is offered at the University of Regina. No elective courses are offered in surveying nor in graphics and computing streams at any university (i.e., all offered courses in these two streams are core courses). The only university that offers elective courses in math and its applications is the Polytechnic of Montreal. The maximum number of elective courses is offered at the Polytechnic of Montreal in environmental engineering stream (i.e. 20).

3.5. Comparison of Accreditation Units (AU) at UofA with CEAB requirements and the other universities across Canada

According to the CEAB, quantifying the curriculum content of engineering programs can be performed using accreditation units (AU). Each AU is equivalent to one hour lecture or two hours of laboratory work or tutorials. The objective is to assure that each engineering graduate receive the minimum exposure in various areas including mathematics (195 AU), natural science (195 AU), complementary studies (225 AU), engineering design (225 AU), engineering science (225 AU), combined mathematics and natural science (420 AU), engineering science and design (900 AU). In total, 1950 accreditation units is required for each engineering program. The civil engineering program at UofA offers 312.57 AU for mathematics, 231.5 AU for natural science, 319.7 AU for complementary studies, 319.6 AU for engineering design, 853.9 AU for engineering science, 544.3 AU for mathematics and natural science and 1220.8 AU for engineering science and engineering design and the total of 2101.4 AU for 2019-2020 academic year. Unfortunately, we did not have access to the AU of the eight other universities-comparison was only made between the AU of the UoA with data provided in the latest research [6] conducted by Engineers Canada on accreditation units of 184 engineering programs across Canada. That study published the mean values of 295.2 AU for mathematics, 295.7 AU for natural science, 313.7 AU for complementary studies, 363.7 AU for engineering design and 749.4 AU for engineering science among studied universities. The mean value of total AU for the studied programs was 2125.

Table 2: Distribution of core and elective courses of each stream among universities

Streams	Courses	Alberta	Calgary	Windsor	Regina	Toronto	McGill	UBC	Waterloo	Montreal	Total
Water Resources	Elective	2	0	1	3	2	7	5	2	7	29
	Core	2	2	3	5	3	2	3	2	5	27
Environmental Engineering	Elective	2	2	1	1	9	9	6	5	20	55
	Core	2	1	2	5	3	1	3	2	2	21
Structural Design	Elective	2	2	1	1	4	3	9	5	4	31
	Core	1	1	3	0	2	2	2	1	2	14
Transportation	Elective	2	2	1	2	2	4	2	3	4	22
	Core	1	1	2	1	2	1	1	2	1	12
Geotechnical Engineering	Elective	2	1	1	0	7	1	4	2	8	26
	Core	2	2	3	2	3	2	3	2	3	22
Construction Engineering	Elective	2	1	0	0	2	2	3	1	0	11
	Core	1	1	1	1	2	2	1	1	2	12
Math and its Application	Elective	0	0	0	0	0	0	0	0	12	12
	Core	8	6	7	6	6	8	7	6	6	60
Mechanics and Structural Analysis	Elective	0	1	0	0	2	2	2	3	0	10
	Core	5	4	6	3	3	3	3	5	5	37
Chemistry and Materials	Elective	0	0	0	1	0	3	0	0	0	4
	Core	4	3	3	2	3	2	4	2	1	24
Surveying	Elective	0	0	0	0	0	0	0	0	0	0
	Core	2	0	1	2	1	1	1	0	2	10
Graphics and Computing	Elective	0	0	0	0	0	0	0	0	0	0
	Core	2	2	1	2	2	2	2	1	3	17
General Design	Elective	0	0	0	0	0	0	0	0	0	0
	Core	0	1	2	2	1	1	2	2	1	12

A comparison of accreditation units was performed between UofA and CEAB as well as UofA and Engineers Canada report (Fig 2). The maximum difference (628.9 AU) was noticed for engineering science between UofA and CEAB limit, demonstrating a higher attention to this area at UofA. However, comparison of AU between UofA and Engineers Canada report showed that natural science and engineering design at UofA were 64.2 and 44.1 units below the mean of 184 programs. The total AU offered by UofA was 23.6 units below the mean value mentioned in the report. No data was provided for mathematics and natural science as well as engineering science and engineering design in the Engineers Canada report to include in Fig. 2.

* M: Mathematics, NS: Natural Science, CS: Complementary studies, ED: Engineering Design, ES: Engineering Science, M+NS: mathematics and natural science, ES+ED: engineering science and engineering design

Fig 2. Comparison of accreditation units between UofA and CEAB as well as UofA and Engineers Canada report

3.6. Limitations

While this study provides comprehensive data on the curricula of major universities across Canada, there are a few limitations. One limitation is that the course syllabi differ among universities. There is a major discrepancy in the course descriptions – some very detailed and others very general – for courses with the same content, making direct comparisons difficult. Also in some of the streams, the course syllabus covers more than one stream (e.g. Geo-Environmental Engineering offered as a technical elective at UBC), making it difficult to assign them in a specific stream. However, such courses can effectively reduce the number of courses and also provide a better overview of interactions between multiple streams, mirroring the reality of the engineering profession. This also prevents over-specialization, which should not be the purpose of undergrad-level programs. This study did not analyze complementary studies courses, inter-disciplinary courses, or Impact of Technology on Engineering courses, which are all mandatory courses within any Civil Engineering curriculum under CEAB. The framework presented in this paper is based on the discipline subject content. We acknowledge that connecting the graduate attributes to the

subject content would improve the work's relevance to Canadian Engineering audience. However, it was not addressed here as it was out of the scope of this work and will be investigated in future studies.

4. CONCLUSIONS

Comparing the curricula of different Canadian Universities reveals that discrepancies exist between programs, especially in number of courses and electives offered. However, allowable number of electives is almost consistent among programs. Overall, there is a need for a more defined Civil Engineering curriculum, and more attention should be paid to technical electives and design project courses. Some universities pay less attention to a particular stream in comparison with the average, which can be identified as a gap in their curriculum and improved in the future. A capstone design project, which is multidisciplinary and covers multiple areas of specialty (or streams), is the predominant approach followed by the majority of universities.

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