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PAPER

Investigating Canadian Engineering Students' Perceptions of Graduate Attributes: Frequency, Criticality, and Relative Importance

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ABSTRACT

This study investigates the perceptions of Canadian engineering students regarding the frequency and criticality of the 12 graduate attributes (knowledge, skills, values, and behaviors that engineering students are expected to demonstrate upon graduation) outlined by the Canadian Engineering Accreditation Board (CEAB). This study aims to assist engineering educators in gaining a better understanding of students' expectations regarding how engineering competencies will be demonstrated in practice. This information can guide the improvement of engineering curricula and help engineering programs meet accreditation requirements for continuous enhancement. Descriptive and test statistics were used to analyze a quantitative survey administered to 340 undergraduate engineering students at a large Canadian university. Findings suggest that the students perceived the frequency and criticality of most graduate attributes differently. Individual and teamwork, communication, professionalism, lifelong learning and engineering tools, were viewed as more frequent than critical, while ethics and equity, impact of engineering, investigation, and design were perceived as more critical than frequent. The study also found that communication, individual and teamwork, and problem analysis were perceived as the graduate attributes with the highest relative importance (frequency multiplied by criticality), which is consistent with the literature.

KEYWORDS

engineering competencies, student perceptions, undergraduate students, quantitative survey, Canada

1 INTRODUCTION

Today's world and work environment are becoming more diverse and complex. Calls have been made for engineering graduates to have more holistic skill sets beyond technical knowledge [1, 2] so they can sustainably, equally, ethically, and justly

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contribute to the economy and address many of the wicked problems facing our societies today [3–5]. Additionally, engineers inherently need to integrate and utilize diverse types of knowledge to solve these complex problems and "meet people's needs and wants" [6, 7]. Fortunately, many accreditation boards worldwide have required engineering programs to demonstrate that their graduates have technical and "social" competencies, although there is still room for improvement [8]. These include students' ability to work in teams, use effective communication skills, and understand their ethical responsibilities and the impact of their work on society. In this way, engineering educators can help students become holistic engineers [9, 10]. Competencies that engineering graduates are required to demonstrate include knowledge, skills, and attitudes (KSAs), behaviors, and values that enable them to make informed decisions, take effective action, and act skillfully in their professional work and personal lives [1, 11].

Since 2009, the Canadian Engineering Accreditation Board (CEAB) has established 12 graduate attributes (GAs) that engineering graduates must demonstrate [9]. They are: 1) knowledge base for engineering; 2) problem analysis; 3) investigation; 4) engineering tools; 5) design; 6) individual and teamwork; 7) communication skills; 8) professionalism; 9) impact on society and environment; 10) ethics and equity; 11) economics and project management; and 12) Lifelong learning. These are based on the GAs as defined in the Washington accord by the International Engineering Alliance (IAE), and the ABET (*accreditation board for engineering and technology, inc.*) learning outcomes [10], which are typical requirements of many engineering accreditation boards worldwide. However, although accreditation boards outline the competencies that graduates must have, engineering programs in Canada are responsible for determining the emphasis and focus of each GA in the curricula. This means that faculty must envision, negotiate, and prioritize each GA in the engineering curriculum to best prepare students for various career paths [12]. Therefore, when designing the curriculum and determining priorities, engineering faculty must answer the question, "What is the relative importance of each graduate attribute?" There must be an explicit and clear understanding of the GAs required for an early-career engineer-in-training (EIT) (referred to as early-career engineers in Canada before achieving professional engineering status as regulated by each province [13]), as this is when engineering graduates will first need to demonstrate the GA KSAs [14].

Research on the importance of GAs is crucial because it helps engineering educators make informed decisions about what to emphasize in the curriculum [15]. In this research area, various study populations can offer different insights. For example, investigating the perceptions of industry members [16], engineering practitioners, and alumni [11] can help universities understand external expectations and set targets for each GA. Also, exploring faculty [1] and students' [17] perceptions enables engineering programs to learn more about the internal atmosphere: while faculty perception directly influences curriculum decisions, students' perception helps understand what messages programs are conveying about engineering, what is in the overt and the hidden curriculum (CITE), and how these findings can inform curricular improvements.

Students' perceptions of the competencies required of an engineer can influence what they perceive and value as useful knowledge for that profession [18]. This statement highlights how students' knowledge acquisition process, interpretation of problems, and selection of strategies play crucial roles in solving engineering problems [18, 19]. Additionally, research in educational psychology suggests that students' beliefs and perceptions of knowledge directly influence their understanding of concepts [20], achievements in school [21], self-efficacy [22], and learning strategies [23]. Students' perceptions of engineering competencies can also influence how they perceive the importance of courses, assignments, homework, and projects [24].

This perception can affect their commitment to and choices of courses based on what knowledge they consider valuable.

Understanding students' perceptions of engineering competencies is essential for informing curriculum improvement [6]. This is not about designing the curriculum based on students' perceptions. Instead, it involves identifying and addressing gaps, misconceptions, or discrepancies between students' perceptions (output) and the program's objectives (input) to guide curricular decisions. However, the literature on the importance and emphasis of engineering competencies, or, in our case in Canada, the "GA," is sparse [12], especially from engineering students' perspectives and in the Canadian context [14].

This study aims to investigate students' perceptions of the 12 CEAB GAs at a large research university in Canada. The goal is to assist engineering educators in reflecting on students' expectations and the messages conveyed by the curricula. Specifically, we are interested in students' perceptions of the frequency and criticality of the CEAB GAs. Here, we define *frequency* as the number of times a required attribute would be used in the daily work of an EIT, and *criticality* as the severity of the consequences of engineering work if a specific attribute is used incorrectly. We inquire, "How do undergraduate engineering students perceive the frequency and criticality of each CEAB GA for an EIT in engineering practice?" and "What is the relative importance of each GA based on students' perceptions of their frequency and criticality in engineering practice?" We commence by examining the literature of analogous studies in this field and proceed with our methodology. Next, we present the results and discussion, divided into two sections: 1) students' perception of the frequency and criticality of the graduate attributes; and 2) the relative importance of the graduate attributes for students, calculated by multiplying frequency by criticality. Then, we will summarize the key findings, implications, and future steps for this study.

2 LITERATURE REVIEW

The global literature on the perception of engineering competencies is limited, especially in Canada. This becomes more prominent when we consider the population, context, metrics, and even the competencies being assessed in each study. However, it is possible to draw parallels and gain insights from what has been published.

In a study in the United States [11], a researcher investigated how recent engineering alumni (up to 10 years of graduation) perceived the 11 ABET competencies by asking alumni to rate the importance of each competency in their professional experience. The ABET competencies include: 1) math, science, and engineering skills; 2) experiments; 3) design; 4) teamwork; 5) data analysis and problem-solving; 6) ethics; 7) communication; 8) understanding impact; 9) lifelong learning; 10) contemporary issues; and 11) engineering tools [10]. They surveyed 2115 graduates from a large university in the United States between 1999 and 2006. They found that engineering graduates across 13 disciplines shared similar perceptions of the importance of the ABET competencies, and these perceptions were consistent across demographics and years. They identified three statistically significant clusters, listed here from higher to lower importance: 1) teamwork, communication, data analysis and problem-solving; 2) math, science, and engineering skills, ethics, lifelong learning, design, and engineering tools; and 3) contemporary issues, experiments, and understanding the impact of engineering on society [11].

Five years later, this study was followed by a systematic literature review [12] on the relative importance of various engineering attributes, using the ABET competencies as the framework for the meta-analysis. The authors identified 27 quantitative studies published worldwide between 1990 and 2013 that discussed the importance of engineering competencies. The studies included 60 samples and involved 14,429 respondents. The population was diverse, encompassing engineering practitioners, alumni, students, faculty, staff, and industry representatives. Through this meta-analysis, four statistically significant clusters of competencies were identified. From higher to lower importance, these clusters were: 1) problem-solving, communication, and teamwork; 2) ethics and lifelong learning; 3) math, science, and engineering skills, engineering tools, experiments, data analysis, and design; 4) contemporary issues and understanding impact [12]. When compared to the clusters from the previous study [11], it is possible to notice differences between them. For instance, four clusters worldwide, instead of three in the United States, show a clearer distinction in the perception of the attributes. Additionally, data analysis and design are perceived as less important in [12] than in [11]. However, problem-solving, communication, and teamwork are among the most important competencies, while understanding impact is among the least important in both studies.

Looking only at students, a study [17] in Singapore investigated whether engineering graduates from two different educational paths—polytechnic and junior college—differently ranked the desirability of GAs from employers' perspectives. The study included 21 randomly selected participants, with 8 from junior college and 13 from polytechnic. The final combined ranking of the eight attributes was: communication, teamwork, problem-solving, planning and organizing, technology, self-management, initiative and enterprise, and lifelong learning [17]. Even though not all attributes in this study align with ABET competencies or CEAB GAs, it is worth noting that communication, teamwork, and problem-solving are the top three, as found in both the study in the United States [11] and in the meta-analysis [12]. In this study, importance was implicitly defined as the desirability of employers.

In another study [25], researchers administered a survey to 502 first-year students, with an equal split between engineering and business majors, from a university in Hong Kong. Their goals involved exploring the differences in students' perceived importance of 32 "generic" skills—also referred to as non-technical, professional, soft skills, etc. [25]—and understanding students' motivation for learning them. These generic skills range from critical thinking, problem-solving, and communication to intercultural awareness, awareness of social issues, conflict resolution, and building team cohesion. Even though some of these skills could be grouped and organized according to the ABET competencies, or GAs, the authors did not make this connection. They found that the only skill engineering students rated higher than business students was "IT skills." In this study, it was found that for both engineering and business students, the primary motivation for developing these skills was extrinsic—to enhance their employability [25]. It shows how participants interpret the "importance" of these 32 "generic" skills and perceive them as qualities that employers value rather than as intrinsic to engineering and professional work.

Similar to other studies in this area [1, 11, 12], this study [25] did not provide an explicit definition of the term "importance" concerning generic skills. However, the findings on students' motivations for learning provide valuable insights into how students perceive the "importance" of them. Some of these motivations include becoming more employable, becoming a well-rounded person, having curiosity, meeting academic requirements, learning to learn, and being more adaptable [25]. Therefore, without a clear definition of "importance," participants are left to their own interpretations and motivations, which can cause some inconsistency in the responses.

Moving away from students, a group of researchers [1] investigated the perceptions of science and engineering practitioners and university teaching staff regarding the necessary competencies in the workplace for scientists and engineers. They asked 46 participants to rate on a 7-point Likert scale how important 26 competencies are for engineering and science graduates today and in 10 years. The authors did not directly link the selected competencies to any accreditation requirements, such as ABET or CEAB. However, the top competencies important today and in 10 years—teamwork, communication, and problem-solving [1]—can be directly linked to ABET and CEAB attributes, as well as to the findings in [11, 12, 17]. Also, the least important competencies for both the present and in 10 years were project management and financial literacy, societal responsibility, and environmental sustainability [1]. These can be compared to the CEAB GAs economics, project management, and impact of engineering on society and the environment, respectively.

In a doctoral dissertation [16], the author investigated how various engineering stakeholders perceived the relative importance of the CEAB GAs. She surveyed engineering students (n = 116), faculty (n = 44), and industry members (n = 47) at a research university in Canada between 2015 and 2016. In this study, relative *importance* was determined by multiplying *frequency* and *criticality*. Frequency represents how often the attribute is perceived as needed in engineering practice at the beginning of an EIT career, while criticality indicates the severity of the consequences of not having sufficient competency in an attribute. Even though two variables were surveyed for each GA, the relevant findings and discussions were reported in terms of their significance. She found the most important GAs to be (in order of importance): individual and teamwork, communication, professionalism, knowledge base, and problem analysis. The least important topics were the impact of engineering on society and the environment, followed by economics and project management. Here, we note the literature emphasizing teamwork, communication, and problem-solving as the most crucial skills for engineers. These findings appear to be consistent across various contexts and populations. On the other hand, *contemporary issues*, *economics*, and *understanding the impact of engineering on society and the environment* tend to be perceived as the least important competencies for an engineer, as also noted in the literature reviewed here.

The studies also revealed some trends regarding methodology. All quantitative studies utilized a Likert-like scale to measure participants' perceptions. With the exception of one study [11], all others employed parametric statistics to analyze the results. Additionally, only three studies [11, 12, 16] examined for statistically significant differences in the ranking of the GAs for the same population.

In reviewing the literature, we identified three gaps. First, there is a general lack of explicit definitions for the term "importance." Apart from two publications [16, 17], all other studies, including the systematic literature review [12], failed to provide a clear definition of "importance." Second, the majority of research in this field relied on a single variable to assess participants' perceptions. The exceptions are [16], where the author used *frequency* and *criticality*, and [1], where the authors discussed *importance today* and *importance in 10 years*. When we consider both of these gaps, we understand that participants' perceptions of "importance" in these studies are susceptible to personal interpretations, which is a limitation in several of these studies. Third, the list of competencies in the literature varies significantly, making a direct comparison among studies difficult and sometimes unfeasible.

This study aims to address these gaps. First, it uses the same two parameters [16] for each CEAB GA—frequency and criticality—and investigates if there is any difference between students' perceptions of these parameters. Second, we calculate the relative importance of each GA based on students' perceptions of their frequency and criticality and compare this to previous studies. Specifically, we compare our findings to references [16] because of their similarities in population and survey instrument, and to references [12] due to their extensive scope, comprehensiveness, and comparable list of competencies. Our findings can provide valuable insights for engineering educators looking to enhance their curricula.

3 METHODOLOGY

This study utilizes a quantitative survey research methodology. The survey was developed, tested, and first piloted with physicians [26], and later adapted and piloted with engineering students [16]. This survey is part of a larger questionnaire with open-ended questions on students' perceptions of engineering [27]. However, this publication focuses solely on the quantitative survey and defers the exploration of the open-ended questions to future publications.

The survey was conducted at the University of Manitoba with 400 undergraduate engineering students in 2020. The data was collected in person using a paper-and-pencil format before the COVID-19 pandemic. Students who participated in the survey were those enrolled in two sections of a first-year engineering design course (n = 138) and those enrolled in the following fourth-year courses: the biosystems engineering capstone course (n = 30), the electrical and civil engineering capstone course (n = 85), the civil engineering capstone courses (n = 72), and two mechanical fourth-year courses (aerospace engineering (n = 35 students) and biomechanical devices (n = 40)) in winter term 2020. There were a total of 340 responses (85%).

Participants had up to 30 minutes to rate the frequency and criticality of the 12 CEAB GAs on a 5-point Likert scale. The university's ethics board and the Office of Institutional Analysis approved the study. Between January and March 2020, the researcher (the second author of this paper) was given 30 minutes to attend each class at a time specified by each instructor. Instructors left the classroom for the researcher to administer the study, and students were asked to return the survey either filled out or left blank in a basket placed next to the classroom exit. Participation was optional and anonymous; students were reminded not to include their names or any other identifying information on the survey. Once all the students had returned the surveys and exited the room, the researcher, who was on the other side of the room from the exit, collected the surveys.

The definitions for each GA, *frequency*, and *criticality* were included in the survey and explained to students by the researcher. The GA *frequency* was defined as the rate at which an EIT at the start of their career will engage in a task that distinctly necessitates this graduate attribute [16]. The five levels of the Likert scale were:

1. Rarely: 1–2 times per year;
2. Sometimes: 1–2 times per month;
3. Regularly: 1–2 times per week;
4. Quite often: once per day;
5. All the time, several times per day.

Criticality was defined as "the potential effect on workplace performance for an EIT at the beginning of their career if they do not have a sufficient level of competency for this graduate attribute" [16]. The five levels of the Likert scale were:

1. No consequence: nothing to either correct or repeat;
2. Minor consequence: little or no harm, damage, or inconvenience can be corrected without help;

3. Moderate consequence: notable harm, damage, or inconvenience that may need help to correct;
4. Major consequence: serious harm, damage, or disruption, likely needing help to correct;
5. Extreme consequence: irreversible or irreparable harm or damage resulting in injuries, death, or destruction of material, the natural world, and/or reputation.

3.1 Data analysis of frequency and criticality

To analyze the results for our first research question, "What do undergraduate engineering students perceive as the frequency and criticality of each CEAB GA for an EIT in engineering practice?" We conducted a quantitative analysis using descriptive and test statistics (paired t-tests). This study treated Likert Scale results as parametric data (continuous quantitative data, normal distribution, and symmetric [28]) for the analysis, even though Likert Scale is ordinal data and, by definition, non-parametric (no assumptions are made about the distribution of the data, and can be used with categorical data) [28]. We chose to use parametric statistics as our method of analysis because it provides more meaningful and statistically powerful results than non-parametric statistics for large Likert-scale datasets [29, 30]. This study considers a p-value of 0.05 for statistical significance (confidence level of 95%) for all test statistics analyses.

Additionally, we utilized *individual relative* frequency and criticality to analyze the data. Instead of using the absolute value (ranging from 1 to 5) of a participant's rating, we divided the rating of each GA by the sum of all 12 GAs for each participant. Therefore, the *individual relative* frequency and criticality represent participants' GA ranking (instead of rating) and are displayed as percentages.

This approach solved three issues. First, it removed the ceiling effect [28], where most of the data is clustered near the upper limit of the scale for each item, as illustrated in Figure 1a. Second, it resulted in an approximate normal distribution curve for the data, as the absolute rating could not be approximated because of the ceiling effect, as shown in Figure 1b.

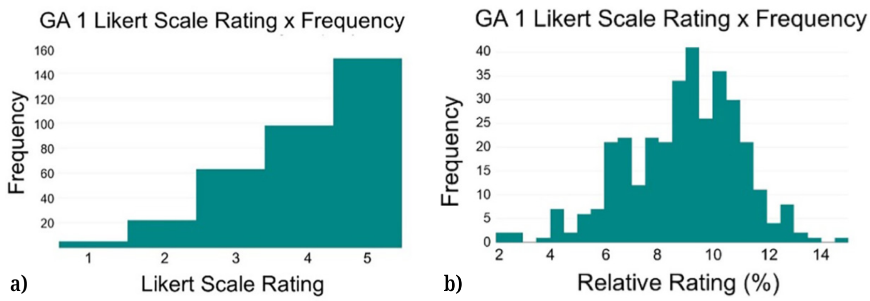

Fig. 1. Comparison of frequency distribution curves between (a) absolute frequency and (b) relative frequency of CEAB graduate attribute 1

Third, it addressed the issue of large differences between "easy" and "harsh" raters, that is, those who give high ratings to all GAs and those who give low ratings to all GAs. For instance, the sum of the frequencies of all 12 GAs ranged from 16 ("harsh raters") to 60 ("easy raters"), with a mean of 46.24 and a standard deviation of 6.14.

The consequence of this approach is that the results do not represent a rating of frequency and criticality, where we could analyze participants' ratings of the GAs from "rarely" to "all the time." Instead, they represent the ranking, allowing us to analyze how each participant ranks each GA relative to the others. In our analysis, participants who assign the same rating to all GAs (e.g., all 3 or all 5) are considered equivalent because they perceive all GAs to have the same frequency or criticality. Hence, in this work, we consider the relative frequency and relative criticality (hereafter referred to as "frequency" and "criticality") to be the standard and represented in percentages.

3.2 Data analysis of the relative importance

To analyze the results for our second research question, "What is the relative importance of each GA based on students' perceptions of their frequency and criticality in engineering practice?" We calculated the importance for each participant using Equation (1) [14]. We first multiplied the *absolute frequency* (F) and *absolute criticality* I of each of the 12 GAs (*i*) to find the *absolute importance* (I).

$$I_i = F_i C_i \text{ [26]} \quad (1)$$

Then, we calculated the *relative importance* (RI) of all GAs' for each participant using Equation (2) [16]. This resulted in a percentage value, with the sum of all RI for each participant equaling 100%.

$$RI_i = I_i / \Sigma I_{1-12} \quad (2)$$

3.3 Limitations

One of the main limitations of this study is the absence of demographic data. Without it, it is not possible to analyze the results in terms of year, gender, or engineering discipline, for example. In this study, we present engineering as a broad field. However, we recognize that engineers can work in various jobs and areas that are likely to require different competencies, and different engineering disciplines have distinct course requirements. Additionally, diverse backgrounds can directly influence how one perceives engineering work. Another limitation of this study is that it was conducted at a single university, which may restrict generalizability and fail to offer a national perspective.

4 RESULTS AND DISCUSSION

In this section, we present the results of the analysis of students' perceptions of frequency and criticality, as well as the relative importance of the CEAB GA.

4.1 Comparison of perceived frequency and criticality of graduate attributes

Table 1 presents each GA along with its corresponding descriptive statistics: frequency, mean, standard deviation, ranking, and t-test comparing each GA with the one directly below its ranking. For example, individual and teamwork (rank 1) are compared to communication (rank 2), while ethics and equity (rank 6) are compared to engineering tools (rank 7). The purpose of this study is to determine if there is a statistical difference between the rankings.

Table 1. Graduate attributes frequency

Graduate Attribute	Mean	SD	Ranking	t-Test (p)
Knowledge Base (#1)	8.87	2.11	5	.088
Problem Analysis (#2)	8.91	1.79	4	.800
Investigation (#3)	7.27	1.87	10	.789
Design (#4)	7.23	2.04	11	.001
Engineering Tools (#5)	8.34	1.97	7	.069
Ind. and Teamwork (#6)	9.79	1.97	1	.562
Communication (#7)	9.71	1.91	2	.002
Professionalism (#8)	9.30	1.79	3	.010
Impact of Engineering (#9)	7.29	1.86	9	.911
Ethics and Equity (#10)	8.57	2.18	6	.190
Eco. and Proj. Mngt. (#11)	6.73	1.83	12	–
Lifelong Learning (#12)	8.00	2.53	8	<.001

Even though it is possible to rank the GAs based on their means, the individual differences between most of them were not statistically significant ($p < 0.05$). Therefore, we grouped the GAs into frequency clusters, as presented in Table 2, to ascertain whether there were statistically significant differences among them. We created the clusters following the approach outlined in [12], where items are grouped according to the statistical differences between the rankings.

Table 2. Frequencies in statistically significant clusters

Cluster	Graduate Attribute	t-Test (p)
A_f	Ind. and Teamwork (#6)	.562
	Communication (#7)	.002
B_f	Professionalism (#8)	.010
C_f	Problem Analysis (#2)	.800
	Knowledge Base (#1)	.088
	Ethics and Equity (#10)	.190
	Engineering Tools (#5)	.069
	Lifelong Learning (#12)	<.001
D_f	Impact of Engineering (#9)	.911
	Investigation (#3)	.789
	Design (#4)	.001
E_f	Eco. and Proj. Mngt. (#11)	–

The first column of Table 2 displays the ranked clusters, followed by their GA names (and numbers), and then their t-test comparing them to the GA immediately below. All GAs within a cluster show no statistically significant internal differences, but all clusters exhibit statistically significant differences from all other GA clusters ($p < 0.05$). For example, there is no statistical difference between the GAs in cluster A_f for individual and teamwork and communication. However, both tare ranked statistically significantly higher than all GAs in group B_f, which are in turn ranked higher than those in group C_f, and so forth.

In this case, there are five statistically different clusters: A_f (individual and teamwork, and communication); B_f (professionalism); C_f (problem analysis, knowledge base, ethics and equity, engineering tools, and lifelong learning); D_f (impact of engineering, investigation, and design); and E_f (economics and project management).

Moving from frequency to criticality, Table 3 displays the GAs and their corresponding criticality mean, standard deviation, ranking based on their means, and t-test between each GA and the one directly below its ranking. In this case, ethics and equity (rank 1) are compared to knowledge bases (rank 2), while investigation (rank 9) is compared to engineering tools (rank 10), and so on.

Table 3. Graduate attributes criticality

Graduate Attribute	Mean	SD	Ranking	t-Test (p)
Knowledge Base (#1)	8.91	2.14	2	.670
Problem Analysis (#2)	8.86	1.89	3	.832
Investigation (#3)	7.98	1.85	9	.096
Design (#4)	8.74	2.31	6	.001
Engineering Tools (#5)	7.73	2.12	10	.455
Ind. and Teamwork (#6)	8.11	2.07	7	.643
Communication (#7)	8.82	2.16	4	.916
Professionalism (#8)	8.04	2.20	8	.738
Impact of Engineering (#9)	8.80	2.26	5	.706
Ethics and Equity (#10)	9.12	2.18	1	.257
Eco. and Proj. Mngt. (#11)	7.29	1.86	12	–
Lifelong Learning (#12)	7.60	2.34	11	.045

Just like the frequency, grouping the GAs into clusters based on their criticalities, as shown in Table 4, is essential to identify statistically significant differences ($p < 0.05$) between them.

Table 4. Criticality in statistically significant clusters

Cluster	Graduate Attribute	t-Test (p)
A_c	Ethics and Equity (#10)	.257
	Knowledge Base (#1)	.670
	Problem Analysis (#2)	.832
	Communication (#7)	.916
	Impact of Engineering (#9)	.706
	Design (#4)	.001
B_c	Ind. and Teamwork (#6)	.643
	Professionalism (#8)	.738
	Investigation (#3)	.096
	Engineering Tools (#5)	.455
	Lifelong Learning (#12)	.045
C_c	Eco. and Proj. Mngt. (#11)	–

Table 4 displays the ranked clusters in the first column, followed by their GA names (and numbers), and then their t-test results comparing them to the GA directly below. All GAs within a cluster show no statistically significant internal differences, but each one is statistically significantly different from all the different GAs in other clusters ($p < 0.05$). The results in Table 4 show that students perceive the criticality of GAs in three statistically different clusters. The GAs in A_c (ethics and equity, knowledge base, problem analysis, communication, impact of engineering, and design) are perceived to have a more critical impact on the work of an EIT than those in clusters B_c (individual and teamwork, professionalism, investigation, engineering tools, and lifelong learning). The only GA in C_c, economics and project management, is perceived to be the least critical.

When we compare Tables 2 and 4, two observations emerge. First, the number of statistically different clusters is higher for frequency (Table 2), which has five, than for criticality (Table 4), which only has three. This demonstrates a more distinct perception of differences in frequency among the GAs compared to criticality. Additionally, economics and project management are the only GAs in a cluster in terms of both frequency and criticality. Based on these findings, we can categorize GAs as either *more critical* (A_c) or *less critical* (B_c and C_c). Meanwhile, we can categorize GAs as *very frequent* (A_f), *frequent* (B_f), *moderately frequent* (C_f), and *less frequent* (D_f and E_f).

Second, it is possible to determine a difference between the GAs students perceive to be more frequent and those they perceive to be more critical in engineering work. Table 5 compares the frequency and criticality of each GA.

Table 5. Difference in students' perception of graduate attributes' frequency and criticality

Graduate Attribute	Freq Mean	Crit Mean	t-Test (p)
Ind. and Teamwork (#6)	9.79	8.11	<.001
Communication (#7)	9.71	8.82	<.001
Professionalism (#8)	9.30	8.04	<.001
Problem Analysis (#2)	8.91	8.86	.729
Knowledge Base (#1)	8.87	8.91	.793
Ethics and Equity (#10)	8.57	9.12	.001
Engineering Tools (#5)	8.34	7.73	<.001
Lifelong Learning (#12)	8.00	7.60	.031
Impact of Engineering (#9)	7.29	8.80	<.001
Investigation (#3)	7.27	7.98	<.001
Design (#4)	7.23	8.74	<.001
Eco. and Proj. Mngt. (#11)	6.73	7.29	<.001

The first column in Table 5 displays the GA name and number. This is followed by the mean for frequency and criticality, respectively, and the p-value (< 0.05) of the t-test for the differences in their values. By comparing students' perceptions of the GAs in terms of frequency and criticality, we can establish that there is no direct correlation between these two measurements. Except for knowledge base, problem analysis, and economics and project management, which showed no statistical difference, all nine GAs' are perceived differently in terms of frequency and criticality.

Individual and teamwork, communication, professionalism, engineering tools, and lifelong learning are all perceived as more frequent in engineering work than critical. It is important to note that the change in communication was not significant enough to move it out of the top cluster. This indicates that, although students perceive it to be more frequent than critical, it still remains among the most frequent and critical GAs. On the other hand, students perceive ethics and equity, the impact of engineering, investigation, and design to have a higher criticality in engineering work than frequency. The largest "positive" differences between frequency and criticality are individual and teamwork and professionalism, which are in the top cluster for frequency (A_f), but in the bottom half for criticality (B_c). In the opposite direction, the impact of engineering and design has the largest "negative" difference between frequency and criticality. They are ranked lower than two-thirds of the GAs' for frequency (D_f) but they are in the top half for criticality (A_c).

These results demonstrate how students perceive the various aspects that contribute to the "importance" of a GA in the work of an EIT. While some GAs may be considered significant due to their frequent necessity, others are deemed crucial because of the consequences of incompetence. For example, the impact of engineering on society and design is perceived to be less frequently needed in the daily work of engineers than eight GAs' (bottom half of *frequency*). However, when these two attributes are needed, the consequences of making a mistake are more severe than in the other six GAs (the top half of criticality). Conversely, individual teamwork and professionalism are perceived to be needed often but have milder criticality.

Knowledge base, problem analysis, and communication are the three attributes perceived to be highly frequent and critical in engineering work. On the other hand, economics and project management are perceived by students to be less frequent and critical compared to the other 11 GAs. Given the low relative score on both aspects, it is worth investigating further whether students do not perceive this GA to be frequent or critical for EIT early in their careers, or if, in fact, they do not perceive economics and project management to be part of engineering at all.

These results can help engineering educators align their teaching methods with students' expectations and perceptions. For instance, if educators want to engage students in a topic related to individual and teamwork, they can emphasize the frequency with which this attribute is required, as it aligns with students' perceptions of it. Conversely, when teaching ethics and equity or the impact of engineering, educators can emphasize the criticality of these attributes. However, it can also serve the opposite purpose. Design instructors, for example, can draw attention to how frequently this attribute is required in the work of an EIT so that students are not caught by surprise when they enter practice.

4.2 Relative importance

Most research on the perception of GAs focuses solely on one metric, typically *importance*. In the systematic literature review conducted by [12], all the metrics from quantitative studies were aggregated based on their importance. The second author's research [16] explored the perceptions of students, faculty, and industry members regarding the frequency and criticality of certain aspects, which were later transformed into *importance* for more in-depth analysis. Therefore, to draw a parallel comparison between the results of this study and the existing literature, we adhered to the process outlined in [16] to calculate the relative importance of the GAs (as detailed in the methodology section).

The study by [16] used the same survey and had a similar population: engineering students (n = 116) from the University of Manitoba. It is important to note that, even though her study population also included engineering faculty and industry members, we used only student data for direct comparison. It enables us to analyze any significant differences in engineering students' perceptions of the importance of GAs at the University of Manitoba from 2016 to 2020. Table 6 compares the relative importance of this study with the one in [16].

Table 6. Comparison of the relative importance between students in this study and [16]

Graduate Attribute	Mean [16], sd	Mean, sd (This Study)	t-Test (p)
Communication (#7)	10.33, 3.75	10.17, 3.43	0.682
Ethics and Equity (#10)	9.35, 4.49	9.37, 3.55	0.962
Ind. and Teamwork (#6)	10.39, 3.87	9.41, 3.20	0.014
Knowledge Base (#1)	8.36, 3.57	9.48, 3.62	0.004
Problem Analysis (#2)	8.92, 3.81	9.44, 3.26	0.187
Professionalism (#8)	9.9, 4.06	8.88, 3.14	0.014
Impact of Engineering (#9)	6.89, 3.87	7.68, 3.02	0.046
Engineering Tools (#5)	8.00, 3.81	7.67, 3.04	0.406
Design (#4)	7.01, 3.94	7.59, 3.19	0.153
Lifelong Learning (#12)	7.50, 4.18	7.40, 3.68	0.813
Investigation (#3)	7.32, 3.81	6.99, 2.71	0.392
Eco. and Proj. Mngt. (#11)	6.03, 3.01	5.91, 2.51	0.707

The names and numbers of each GA are listed in the first column of Table 6. Columns 2 and 3 show the mean and standard deviation of the relative importance for the current study and the study in question, respectively. The last column lists the p-value for the t-test of each GA.

In Table 6, we demonstrate that only four GAs' exhibited statistically significant ($p < 0.05$) changes between the two studies: an increase in students' perception of the relative importance of knowledge base (from 8.36 (3.57) to 9.48 (3.62)) and impact of engineering (from 6.89 (3.87) to 7.68 (3.02)); and a decrease in individual and teamwork (from 10.39 (3.87) to 9.41 (3.20)) and professionalism (from 9.90 (4.06) to 8.88 (3.14)). The other eight GAs did not show statistically significant differences between the two populations. This result indicates that in 2020, students at the University of Manitoba perceived the impact of engineering on society and knowledge base as more important than students in 2016. Conversely, individual and teamwork and professionalism are perceived as less important. Since many elements can influence one's perception of a profession [6], it would be worthwhile to investigate the factors that caused these changes in students' perceptions. For instance, these changes could be driven by internal factors (e.g., curriculum change or recruitment and retention strategies) or external factors (e.g., political, social, cultural, job market, or climate change).

Despite these individual changes, these findings suggest that, in order of perceived importance in this study, communication, ethics and equity, individual and teamwork, knowledge base, problem analysis, and professionalism were, and still are, perceived by engineering students at the University of Manitoba to be more important than the impact of engineering on society, engineering tools, design, lifelong learning, investigation, and economics and project management. These results are aligned with the literature that consistently shows that communication, individual and teamwork, and problem analysis are perceived by different stakeholders—students, faculty, and industry members—to be the most important attributes of an engineer [1, 11, 16, 17].

It is worth noting that the CEAB mandates that Canadian engineering programs allocate a minimum of 71.3% of the curriculum (1320 out of 1850 accreditation units (AU)) to teaching mathematics, natural sciences, engineering sciences, and engineering design [9]. These subjects are closely linked to the GA's knowledge base and design. complimentary studies (which include communication, professionalism, ethics and equity, impact on society, and lifelong learning) should be at least 225 AUs, and the remaining 305 AUs can be allocated at the university's discretion. The way the prescribed 1545 AUs are taught and what is taught in the remaining 305 AUs can vary from program to program according to its priorities and focus.

Therefore, engineering programs need to be aware and explicit about their priorities so they can optimize their efforts in training the engineers they envision. This way, programs can compare the results of studies such as this (including [12] and [16]) to explore whether what students perceive to be important aligns with their expectations and projections. If, for instance, there was an intentional effort to increase the relative importance of the knowledge base at the University of Manitoba, the effort could be considered a success. However, if the university expects students to consider professionalism more important than before, the strategies should be reconsidered.

In Table 7, we directly compare the findings of research studies that closely align with this study in terms of terminology and metrics. In their systematic review of perceptions of engineering competencies [12], the authors identified four statistically significant clusters, which the second author [16] also utilized to group her GAs for comparison. Therefore, we utilize the same approach and comparable clusters (extracted from Tables 2 and 4) to directly compare the results of our study with those of [12] and [16].

Table 7. Comparison of clustered engineering competencies between [12], [16] and this study

Clusters	Top 4 Groups of Eng. Competencies [12]	All Stakeholders' Relative Importance [16]	This Study: Student's Relative Importance
1	Problem Solving	Individual and Teamwork	Communication
	Communication	Communication	Knowledge Base
	Teamwork	Professionalism	Problem Analysis
		Knowledge Base	Ind. and Teamwork
		Problem Analysis	Ethics and Equity
2	Ethics	Ethics and Equity	Professionalism
	Lifelong Learning	Engineering Tools	

(Continued)

Table 7. Comparison of clustered engineering competencies between [12], [16] and this study *(Continued)*

Clusters	Top 4 Groups of Eng. Competencies [12]	All Stakeholders' Relative Importance [16]	This Study: Student's Relative Importance
3	Knowledge base	Investigation	Impact of Engineering
	Engineering Tools	Lifelong Learning	Eng. Tools
	Investigation	Design	Design
	Design		Lifelong Learning
4	Contemporary Issues	Impact of Engineering	Investigation
	Impact of Engineering	Economics and Proj. Mngt.	Economics and Proj. Mngt.

It is important to highlight that the values for [16] in Table 7 represent the means for the entire study population (students, faculty, and industry members, n = 207), while in Table 6 the values are specific to students (n = 116). The population in [12] also includes stakeholders with various demographics and roles (n = 14,429). From Table 7, we can observe that, despite variations in stakeholder populations, years, institutions, and nations, communication, individual and teamwork, and problem analysis (solving) are consistently regarded as the top three important attributes. This aligns not only with research on the perception of these skills but also with research on the nature of engineering work that highlights the importance of communication and teamwork to solve engineering problems [3, 12, 31, 32].

Design, in turn, is consistently ranked in the lower clusters. It would be worth investigating why students rank design relatively lower than most other attributes, given that it has been identified as a key aspect in the nature of engineering, the engineering way of thinking [33], and engineering problem-solving [3, 34]. Design is commonly taught in K-12 settings as a way to build a pipeline to engineering [35, 36], it holds prominence in undergraduate accreditation [9], and many engineering programs across Canada emphasize it by incorporating a "design spine" that connects the entire curriculum [37, 38].

Another relevant finding is the significant difference in students' perceptions of the importance of the impact of engineering on society. In both [12] and [16], this attribute is considered one of the least important among all stakeholders. However, in this study, it is included in an upper cluster. *Here, importance* is determined by two factors: frequency and criticality. When we analyze Tables 2 and 4, we find that *criticality* is driving up the *importance* of the impact of engineering since students still perceive it as one of the least *frequent* attributes. As discussed previously, two factors can influence this change: internal or external to the university. When reflecting on the possible reasons for these differences, it is important to consider events and changes that might have occurred internally and externally at the university between the time of these studies (data in [12] is from 1990–2013, from 2015–2016 in [16], and data in this study is from 2020).

At the University of Manitoba, one internal intervention that might have positively influenced the change in students' perceptions of the impact of engineering on society was a project designed in 2018 by the NSERC Chair in Design Engineering for Sustainable Development and Enhanced Design Integration [39]. The project focused on engineering educators incorporating sustainable development design fundamentals at various levels into their undergraduate courses using the United Nations (UN) sustainable development goals (SDGs) [39]. Including sustainability topics in undergraduate engineering courses might be one possible internal factor that positively influences students' perceptions of the criticality of the impact of engineering on society. Since then, there has been a visible increase in curricular initiatives in engineering education at the University of Manitoba. For instance, courses such as *Technology, Society, and the Future* (ENG 3020) and *Engineering Communication* (ENG 2040) have incorporated topics such as the UN SDGs, respectful Indigenous and stakeholder consultation, leadership, and sustainability.

External factors are always in play. Students must constantly negotiate the preconceived notions they bring to the university regarding the work of engineers with the new understanding they develop through professional enculturation at the university and in the workplace [40]. Some potential external factors that can influence students' perceptions of the criticality of the impact of engineering on society include the growing negative impact of global climate change, the urgent need for engineers to contribute to solving this crisis, and public debates on the societal effects of technologies such as artificial intelligence, public surveillance, and social media [41].

It is worth noting that the results presented in Table 7 suggest no apparent correlation between the number of AUs engineering programs are required to allocate for specific attributes and students' perceptions of those attributes. For instance, as discussed previously, design has prominence in the assignment of AUs, but it is commonly perceived as the least important GA. Conversely, communication and individual and teamwork must share between 12 and 28% (225–530 of 1850) of the AUs with the other three GAs, but they are consistently perceived as the most important GAs.

5 CONCLUSIONS

Research on stakeholder perceptions of engineering competencies can help engineering educators make informed decisions about curriculum design and what to emphasize. Different study populations can provide unique insights. For instance, while industry members and engineering practitioners can identify what is needed in the workplace, engineering students' perceptions can help engineering programs understand the message students receive about engineering vis-à-vis the curriculum. The perception of the engineering competencies required during their professional lives can influence students' knowledge acquisition process and learning strategies. This influence extends to course selection and prioritization, as well as decisions regarding extracurricular activities like design teams, internships, or student governance throughout their degree.

This study aimed to investigate students' perceptions of the CEAB GAs' frequency and criticality in the work of an EIT. The findings in this study have implications for both individual engineering educators and engineering programs. This raises the question of the relative importance of the GAs and what measures could be implemented to align students' perceptions of engineering work with the expectations of engineering stakeholders for future engineers. These actions can occur at the micro level (in the classroom) or at the macro level (in the curriculum) by reinforcing and communicating the importance of specific GAs.

We identified that students perceive most GAs differently in terms of frequency and criticality. Five GAs' are perceived as more frequent than critical in the work of an EIT: individual and teamwork, communication, professionalism, engineering tools, and lifelong learning. On the other hand, four GAs are perceived to have a higher criticality when compared to their frequency: ethics and equity, impact of engineering, investigation, and design. Overall, knowledge base, problem analysis and economics, and project management did not present any statistically significant difference between frequency and criticality. These results suggest that students can perceive a GA as important either because it is required frequently or because it can have critical consequences if applied incompetently. In either case, educators can leverage this perception to increase student engagement in topics related to specific attributes.

In terms of importance, our study found that communication, knowledge base, problem analysis, individual and teamwork, and ethics and equity are the top competencies. These results reinforce that communication, individual and teamwork, and problem analysis are perceived to be the main competencies required by engineers. This aligns with the literature on the perception of engineering attributes and the nature of engineering work. It suggests that engineering educators have been able to align, at least at a higher level, students' expectations of the main attributes they will need as an EIT. It shows that students recognize the interpersonal and collaborative nature of engineering and that these attributes represent the majority of their work.

Design, on the other hand, was ranked in the second last group in this study, as well as in other studies in the literature, in terms of importance. This is concerning because design is one of the central aspects of the engineering profession and has been emphasized in many curricula across Canada. It is worth investigating the factors influencing this perception and developing measures to address it.

We also found that the impact of engineering on society is perceived as significantly more important in this study compared to previous ones. This increase in importance was driven by criticality. Even though students do not perceive this attribute as frequently needed in their work, they believe it can have critical impacts if ignored. Students perceiving the impact of engineering on society as more important than before is particularly relevant, given the role engineering has played in both the positive and negative consequences of technological development. By educating future engineers who are aware of the criticality of the impact of their work, we, as a society, have a better chance of addressing pressing social and environmental issues without creating additional problems.

5.1 Next steps

The next steps of this study will include adding a qualitative component to gain a more nuanced and detailed understanding of students' perceptions of engineering. This will involve exploring the open-ended questions in the questionnaire. Future work also involves analyzing populations data from three different institutions across Canada, including demographic data. Lastly, a longitudinal study investigating students' perceptions over time would be beneficial to understand the effects of the curriculum on students throughout their years in the program, from the first to the final year.

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