Using content validity measures to evaluate the Biosystems Engineering Program at the University of Manitoba

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ABSTRACT

An exploratory case study was designed to determine the relative importance of the Canadian Engineering Accreditation Board (CEAB) graduate attributes as perceived by University of Manitoba engineering stakeholders. Findings were used to examine the content validity of the Biosystems Engineering program. The overarching objective was to explore how graduate attribute emphasis in engineering programs reflect graduate attribute importance reported by key stakeholders. *Problem Analysis, Investigation, Design, Communication Skills, Impact of Engineering on Society & the Environment*, and *Use of Engineering Tools* had similar expected (mean relative importance) and observed (content and assessment program coverage) data percentages. The gap was wider for other graduate attributes, with the most surprising being *Knowledge Base*. Overall, the pattern of results suggests that various professional attributes (e.g., *Professionalism, Ethics & Equity,* and *Lifelong Learning*) should be more prominent in content and assessments within an engineering program. Recommendations to improve methods to assess content validity in engineering programs are discussed.

RÉSUMÉ

Une étude de cas exploratoire a été conçue pour déterminer l'importance relative des qualités requises des diplômés du Bureau canadien d'accréditation des programmes d'ingénierie (BCAPI) tels que perçus par les intervenants en génie de l'Université du Manitoba. Les résultats ont été utilisés pour examiner la validité du contenu du programme de génie des biosystèmes. L'objectif principal était d'explorer comment l'importance des qualités requises des diplômés dans les programmes d'ingénierie reflète l'importance de ces qualités signalée par les principales parties prenantes. *L'analyse des problèmes, la recherche, la conception, les compétences en communication, l'impact de l'ingénierie sur la société et l'environnement ainsi que l'utilisation des outils d'ingénierie* présentaient des pourcentages de données attendus (importance relative moyenne) et observés (contenu et couverture du programme d'évaluation) similaires. L'écart était plus important pour les autres qualités requises des diplômés, le plus surprenant étant la *base de connaissances*. Dans l'ensemble, la tendance des résultats suggère que divers qualités professionnels (p. ex., *le professionnalisme, l'éthique et l'équité, et l'apprentissage continu*) devraient occuper une place plus importante dans le contenu et les évaluations d'un programme de génie. Les recommandations visant à améliorer les méthodes d'évaluation de la validité du contenu des programmes d'ingénierie sont discutées.

KEYWORDS

Program evaluation, CEAB graduate attributes, biosystems engineering, content validity, relative importance, exploratory case study.

MOTS CLÉS

évaluation de programme, qualités requises des diplômés du BCAPI, génie des biosystèmes, validité du contenu, importance relative, étude de cas exploratoire.

CITATION

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INTRODUCTION

There is global agreement on the critical role of engineering competencies for engineers of the 21st century. This is demonstrated by engineering accreditation boards around the world that have moved away from solely quality assurance models focused on documenting inputs in engineering programs to outcomes-based models concentrated on assessing students' competencies, improving their learning, and supporting a cycle of continual program improvement (Almarshoud 2011; Oliver 2013; Prados et al. 2005). Accredited engineering programs are required to demonstrate that their programs are designed to teach students the knowledge, skills and values identified in defined technical and non-technical (i.e., 'professional') engineering competencies, and their graduating engineering students are competent in these areas (Davis et al. 2002; Olds et al. 2005).

Research shows that there is a growing awareness of the value of outcomes-based pedagogical practices, not only for enhancing student learning (Heinricher et al. 2002), but also for enriching program quality (Prados et al. 2005). Outcomes-based education is a process that continually focuses on student learning and demands institutions to be accountable to the evidence of that learning (Driscoll and Wood 2007); outcomes-based systems are designed to isolate, gather, examine, and report data for evidence of student learning. Outcomes-based pedagogy is meant to be a dynamic process: a continuous cycle of assessment and program improvement (Davis et al. 2002; Dew et al. 2011; Fredericks Volkwein et al. 2004; McCahan et al. 2011; Moskal 2008). Outcomes are the parts of a student's development that an institution endeavors to impact through their educational programs and procedures (Soundarajan 2002). They describe what students are expected to know and do by the time of graduation. The outcomes of a student's education are affected by who they are when they come into an institution, what they experience both in their courses and as a result of the program, and how all of those experiences and influences work together to form their understanding of, and attitudes towards learning overall, and in particular, towards their field or profession (Rogers 2000).

Engineering learning outcomes were first identified in 1996 by the Accreditation Board for Engineering and Technology (ABET), the body responsible for accrediting American (and other) college and university programs in applied science, computing, engineering, and engineering technology. They were developed in response to a number of reports and movements to disrupt the engineering curricula and make room for reform (Borrego and Bernhard 2011; Oliver 2013; NEERC 2006). They represented the competencies critical for preparing engineering graduates for professional practice in a multifaceted and changeable world (Passow 2012). In 2013, they were adopted by the signatories of the Washington Accord as a reference point to measure 'substantial equivalence' of individual country's accreditation requirements (International Engineering Alliance 2014). Although these engineering competencies are identified, educators are responsible for defining them, as explained by Passow and Passow (2017, 475): 'Under Washington Accord or ABET accreditation requirements, *faculty must envision, collectively articulate, and prioritize the competencies* that students should gain from their educational program to prepare for life and myriad career paths' (emphasis ours).

These requirements are now consistent with engineering education in Canada. Previous to the adoption of outcomes-based assessment, Canadian engineering schools traditionally offered courses designed using inputs-based systems (Wolf and Stiver 2011) and evaluated their programs by documenting these inputs. This typically included tracking time spent in a lab, classroom and tutorial contact hours, and personnel, such as number of sessional instructors, instructors with PhDs, and professors registered as professional engineers. Among other input data, programs were (and still are) required to measure Accreditation Units (AUs), and record the hours devoted to engineering fundamentals such as mathematics, natural sciences, engineering science, engineering design, and complementary studies. In 2009, the Canadian Engineering Accreditation Board (CEAB) initiated an outcomes-based approach for engineering curriculum development and assessment (Frank et al. 2011; Frank and Fostaty-Young 2011; Wolf and Stiver 2011). Since 2014, Canadian institutions seeking CEAB accreditation are responsible for developing systematic and valid curricula, and outcomes-based pedagogical strategies and assessment tools that are constructively aligned with their educational objectives and teaching methodologies (McGourty et al. 1999; Biggs 1999; Biggs 2013). They must create and implement an assessment protocol to evaluate students' attainment of the program's educational objectives and the accreditation outcomes mandated, and these results must ideally be used to incur program improvement (Davis et al. 2006; Popp et al. 2012; Rogers 2000; Soundarajan 2002).

The outcomes that are required of Canadian engineering graduates are identified by 12 CEAB graduate attributes and can be linked to the ABET Criterion 3 Student Outcomes and the Washington Accord Graduate attributes. They consist of what has been controversially defined as the 'technical' engineering competencies (graduate attributes 1 – 5), and the 'professional' or non-technical competencies (graduate attributes 6 – 12) (for a discussion on engineering technical and professional skills, see Shuman et al. 2005). They are:

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Use of engineering tools
5. Design
6. Individual & teamwork
7. Communication skills
8. Professionalism
9. Impact of engineering on society & the environment

10. Ethics & equity
11. Economics & project management
12. Lifelong learning

To achieve accreditation, Canadian institutions, like institutions accredited by ABET (Felder and Brent 2003), are faced with the challenge of evaluating their programs and improving them to satisfy CEAB requirements. This is difficult, as CEAB has provided a list of graduate attributes, but no baseline, and no way to 'calibrate' improvements (Pons 2016, 535). The relative importance of the CEAB graduate attributes is not given, which is critical when improving existing curricula to demonstrate graduate attribute competencies.

LITERATURE REVIEW

Research conducted to ascertain how to prioritize engineering competencies is found in Australia, New Zealand, the UK, Europe, and the USA. Nguyen (1998) surveyed Australian engineering students, academics, and industry to determine their views on the most essential competencies for the 'modern' engineering (p. 65). Participants ranked a group of 7 engineering generic skills and attributes each with several sub-groups of specialized skills on a hundred-point scale. Findings were divided into three groups: *essential, desirable,* and *advantageous*, determined by the rating overlaps between the three stakeholder groups. *Fundamental engineering knowledge*, including *practical and technical skills*, was found to be most essential, in addition to *understanding the impact of engineering on the environment*. Nguyen (1998) argued that due to the 'remarkable difference in rankings between industry and the other two groups… engineering education is producing a different engineer to that desired by industry, and that engineering education is perhaps failing to meet market demand' (p. 67, p. 69).

Male, Bush and Chapman (Male 2010; Male et al. 2010, 2011a, 2011b) surveyed 300 Australian engineers to confirm findings from international studies on competency deficiencies in *project management skills, communication* and *leadership* and *practical application* and *business skills* in the Australian context. Participants rated 64 competencies derived from the literature for importance to their jobs and gave perceptions of competency deficiencies via open ended questions. The authors used the importance ratings to devise a competency model for identifying generic competencies required by engineering students. *Communication, teamwork, self-management, professionalism* and *ingenuity* had the highest competency factor scores (Male 2010); *practical engineering, engineering business competencies, communication skills, self-management and appropriate attitude, problem solving,* and *teamwork* had dominant competency deficiencies (Male et al. 2010). Other Australian research on engineering competencies using survey methods confirmed deficits in *emotional intelligence* (Scott and Yates 2002); *accountability, teamwork, communication, interpersonal skills* and *skills to advocate and influence* (Bons and McLay 2003); *communication* and *graduate business skills* (Ashman et al. 2008); and *communication, problem solving, time-management, teamwork, application of knowledge in the workplace, ability to cope with stress,* and *capacity to learn* (Nair et al. 2009). Overall, many of the deficiencies were found in the professional skills.

Pons (2016) conducted a large-scale survey of practicing engineers in New Zealand to determine what engineering management topics should be taught to students. Thirty-three professional skills topics were provided based on the Washington Accord graduate attributes and the literature, and participants were simply asked to select all that apply (note that technical competencies were not included). The relative importance of engineering management topics was determined by the frequency they were chosen by participants. *Communication* and *project management* were selected most frequently.

Bodmer et al., as cited in Male et al. (2010), surveyed 1372 engineers in Europe and the USA for competency ratings of importance and graduate performance, finding gaps in *communication, leadership* and *social skills*. Robinson et al. (2005) conducted a mixed methods study of one company in the UK to identify the most important *future* competencies for Design engineers. Participants rated the importance of 49 competencies based on their current job, and their perception of their job 10 years into the future. Findings from qualitative interviews supported the development of the questionnaire, as well as identifying future top-rated competencies using critical incident questioning following the questionnaire. Criticality ratings for each competency was based on the proportion of interviewees who indicated a competency during the post interviews. The future competency profile derived were 42 competencies divided into six groups in order of importance: *personal attributes, project management, cognitive strategies, cognitive abilities, technical ability,* and *communication* (Robinson et al. 2005).

In the USA, Passow (2012) found engineering alumni ranked *teamwork* and *communication* as two out of four top competencies in their professional practice. *Data analysis* and *problem solving* were the other. Passow and Passow (2017) conducted a comprehensive, global, systematic literature review on engineering competencies in engineering practice to 'answer the practical question of curriculum design: What competencies should undergraduate engineering programs emphasize?' (p. 476), by 'Defining the nature of engineering work and the generic competencies required in engineering practice' (p. 504). They identified 16 engineering competencies important to engineering practice, which divided into four clusters. They compared these to, and expanded them from, the Washington Accord competencies. *Problem solving, communication* and *teamwork* were the top competencies.

Overall, top competencies and competency deficiencies in these studies were largely found in the engineering 'professional' skills. As well, all of the studies discussed focus on 'expected' or 'desired' performance, but none of them examine 'observed' performance in engineering education programs. In Canada, while numerous publications on the CEAB graduate attributes have explored important questions pertaining to classroom assessment (Sullivan and Brennan 2018), there is an absence of research on how to prioritize the CEAB graduate attributes, and an absence of research that explores, from a content validity perspective, the basic question of how much each graduate attribute should be covered and assessed within engineering programs. Canadian engineering faculty need to have a clear understanding of how the graduate attributes manifest for Engineers-in-Training (EITs) at the beginning of their career, as this is the point at which newly graduated engineering students will first employ the graduate attributes in practice. The relative importance of each of the CEAB graduate attributes to the practice of EITs will apprise engineering educators how to emphasize the graduate attributes in engineering curricula. This knowledge can then be used to evaluate and improve engineering programs. This, 'process-oriented' question can be answered in two basic steps: (1) identifying the expected level of importance of each CEAB graduate attribute, and (2) comparing, for each graduate attribute, the expected level of importance to what is observed in the program. While tools reflecting the expected level of relative importance have been developed in other disciplines such as Medicine (Stutsky et al. 2012) and Nursing (Renaud 2019) in Canada, it appears that a comparable tool has not been developed in Engineering.

PURPOSE

This engineering education research article reports on the second phase of an exploratory case study conducted to explore how the emphasis on graduate attributes in the engineering programs at the University of Manitoba reflect their reported importance by key engineering stakeholders for an Engineer-in-Training at the beginning of their professional practice. The purpose of the study was to (1) to develop a criterion measure of relative importance for each of the graduate attributes, and (2) to assess the content validity of the Biosystems Engineering program by comparing the expected importance to the observed levels of content coverage and assessment, for each CEAB graduate attribute. The study was executed in two phases. The first phase was designed in part to determine the relative importance of the CEAB graduate attributes for an EIT at the beginning of their career as perceived across three University of Manitoba engineering stakeholder groups: students, faculty, and Manitoba industry members belonging to the group affiliated with the Price Faculty of Engineering, *Friends of Engineering*, an external organization comprised of senior-level executives, managers, team leaders and engineering champions who support engineering education and strong relations between Manitoba industry and the Price Faculty of Engineering (see https://friendsofengineering.ca/about-us/). The second phase was designed to evaluate the content validity of the Biosystems Engineering program as measured by the mean relative importance of the CEAB graduate attributes determined by engineering stakeholders. Findings, such as the differences in relative importance ratings between stakeholders, are reported on in other work (see Seniuk Cicek and Renaud 2019). This paper presents the findings from phase 2 of the study, the content validity evaluation of the Biosystems Engineering program, expanded here from Seniuk Cicek et al. (2018). This phase was guided by the research question: *In the Biosystems Engineering program, how do the percentages of course content coverage and course assessments of the CEAB graduate attributes compare with their perceived relative importance by all engineering stakeholders*? The purpose of this study is to inform the improvement and development of authentic outcomes-based engineering curricula informed by engineering practice.

METHODS

An index of relative importance was compared to the total percentages of core course content coverage and course assessments of the 12 CEAB graduate attributes in the Biosystems Engineering program to evaluate the content validity of the program.

Department of Biosystems Engineering, University of Manitoba

The Department of Biosystems Engineering is one of five engineering programs at the University of Manitoba, a large research university in Winnipeg, Canada, and is an academic unit in the Faculty of Agricultural & Food Sciences. It offers both undergraduate and graduate level programs, supporting approximately 160 undergraduate students and 80 graduate students each year. The undergraduate program is housed within and accredited through the Price Faculty of Engineering. The Biosystems undergraduate program comprises 45 required courses, some of which are taught within the department, and others outside, within the Faculties of Engineering, Arts or Science (see Appendix A for the Biosystems 5-year model). Thirty-five of the courses are considered core courses, with the remaining 10 courses fitting into four categories of electives (i.e., two science electives, three Biosystems design electives, three complementary studies electives, and two free electives). In this study, the 35 core courses were evaluated to determine the content validity of the Biosystems Engineering program.

Index of relative importance

A closed-ended rating survey was designed to determine the relative importance of the CEAB graduate attributes as perceived by engineering stakeholders at the University of Manitoba (i.e., students, faculty, and Manitoba industry members in partnership with the Price Faculty of Engineering through the organization, *Friends of Engineering*). Table 1 shows the distribution of stakeholder participants by engineering area.

Biosystems Engineering was represented by 13.2% of study participants. Overall, participation rates were reflective of student representation in the Biosystems

Table 1. Phase 1 stakeholder participation by engineering department.

Stakeholder	Population	Participation All Areas	BIOE	CIVL	COMP	ELE	MECH	EPP
Student	235	125 (53.2%)	12	50	16	31	16	0
Faculty	91	46 (50.5%)	11	7	3	7	14	4
Industry	70	48 (68.6%)	6	15	5	10	11	1
Total	396	219	29	72	24	48	41	5
Total %	100	55.3	13.2	32.9	11.0	21.9	18.7	2.3

Note: BIOE (Biosystems); CIVL (Civil); COMP (Computer); ELE (Electrical); MECH (Mechanical); EPP (Centre for Engineering Professional Practice and Engineering Education).

Engineering program with less than 1% difference between student capacity and Phase 1 participation rates. Eleven out of 14 Biosystems faculty participated, at a 78.6% rate. Within the Biosystems Engineering program, while the number of student and industry participants could have been greater, these two sub-groups were of sufficient size to provide a fairly stable estimate of the mean importance ratings. It is unlikely that ratings from additional participants would result in a notable change for the mean importance for any of the attributes.

Participants were given a list of the 12 graduate attributes and the CEAB definition for each attribute (see Appendix B for CEAB Graduate Attributes Rating Form). They rated each graduate attribute along a 5-point Likert scale for frequency (Table 2), and a 5-point Likert scale for criticality (Table 3).

The relative importance was calculated as follows: Data were collected on the perceived frequency of a graduate attribute for an EIT in engineering practice, i.e., *how often an EIT at the beginning of his/her career will perform a task that clearly requires a graduate attribute* (Table 2), and the perceived criticality of a graduate attribute, i.e., *the potential effect on workplace performance for an EIT at the beginning of his/her career if he/she does not have a sufficient level of competency for this graduate attribute* (Table 3) (see Seniuk Cicek et al. (2017a) for a more detailed account of survey development).

The mean perceived absolute importance (I) of each graduate attribute (attribute *i*) for each stakeholder was calculated by multiplying the frequency (F) and the criticality (C) of attribute *i*, as represented in the formula - $I_i = F_iC_i$ (Stutsky et al. 2012). The mean percentage of each graduate attribute's absolute importance to the total absolute importance of all graduate attributes was computed to develop an index of relative importance. As the relative importance of each graduate attribute was fairly similar across each of the three stakeholder groups, the perceptions of all engineering stakeholders combined was used as a criterion measure for assessing the content validity of the Biosystems Engineering program.

Content validity evaluation

The second purpose of this study was to evaluate the measure of content validity of the Biosystems Engineering program in order to inform the improvement and development of authentic outcomes-based engineering curricula. Ro et al. (2015) describe content validity within the domain of validity:

> "Evidence based on test content refers to the extent to which a scale's items, in the aggregate, constitute a representative sample of the topic's content domain. Do the items reflect what has been defined as "contextual competence" (Suen, 2008; Trochim, 2006)? To answer the question, content experts are consulted and their professional judgment is taken to reflect the degree of what was traditionally called "content validity." (p. 37-38)

Content validity shows whether or not the content within the instrument is demonstrative of the intended concept to

Table 2. Frequency scale.

1	2	3	4	5
Rarely	**Sometimes**	**Regularly**	**Quite often**	**All the time**
1-2 times/year	1-2 times/month	1-2 times/week	once per day	several times/day

Table 3. Criticality scale.

1	2	3	4	5
No consequence (Nothing to either correct or repeat)	**Minor consequence** (Little or no harm, damage or inconvenience, can correct without help)	**Moderate consequence** (Notable harm, damage or inconvenience, may need help to correct)	**Major consequence** (Serious harm, damage or disruption, likely need help to correct)	**Extreme consequence** (Irreversible or irreparable harm or damage, resulting in injuries, death or destruction of material/natural world, and/or reputation)

be measured (Gliner et al. 2009, p. 166). In this research, the content validity of an engineering curriculum is being measured by comparing the overall percentage that each CEAB graduate attribute is taught and assessed in the core Biosystems Engineering program to the mean relative importance of the graduate attributes as determined by all engineering stakeholders in this case. The assumption is that the more relatively important a graduate attribute is, the more 'representativeness' it should have in the curriculum, thereby establishing a measure of content relevance (Jonsson and Svingby 2007, p. 136).

Content coverage and assessments for the 12 CEAB graduate attributes in the Biosystems Engineering program

Faculty teaching core courses in the Biosystems Engineering program were asked to identify, in their judgment, what percentage of time they spend teaching and what percentage of time they spend assessing the applicable CEAB graduate attributes in their course. For this purpose, the *Teaching Faculty Course Content Questionnaire* was developed (see Appendix C). Questionnaires were prepared individually for each course based on the targeted CEAB graduate attributes derived from accreditation documents and the previous work done to validate and implement a set of graduate attribute rubrics in the Biosystems Engineering curriculum (see Seniuk Cicek et al. 2017b). Faculty were asked to confirm or correct the graduate attributes identified for their course at the outset of the questionnaire, and then answer the subsequent questions based on the confirmed graduate attributes. Prior to collecting these data, the Head and Associate Head of the Department of Biosystems Engineering reviewed pilot versions of the questionnaire and made minor revisions to the instructions to improve clarity, and to ensure it could be completed within the expected brief length of time.

There are 35 core courses in the Biosystems program. All faculty members teaching courses in the Department of Biosystems Engineering (n=14) as well as faculty from other departments in the Price Faculty of Engineering who taught courses required by the Biosystems Engineering program (n=7) filled out the *Teaching Faculty Course Content Questionnaire* during the Fall 2017 term. The data collected from the questionnaire delineated both the percentage of time spent teaching and assessing each of the graduate attributes based on faculty members' professional judgment (Ro et al. 2015).

For the courses taught outside the Department of Biosystems Engineering (n=14) – courses offered either within the Price Faculty of Engineering or in the Faculties of Arts or Sciences – where faculty did not fill out the questionnaire, the first author used Price Faculty of Engineering accreditation documents to ascertain which CEAB graduate attributes were taught and assessed in each course and estimated the percentage of time spent on each. It was found that the percentage of assessments for each graduate attribute was delineated in these documents; however, the percentage of time spent teaching these graduate attributes was not. If the percentage of time spent teaching each of the applicable graduate attributes could not be clearly determined from additional documentation (i.e., course syllabi), the first author assumed that the percentage of time spent teaching the graduate attributes was equal to the percentage of assessments for each.

The total percentages of core course content coverage and course assessments for each of the 12 CEAB graduate attributes in the Biosystems Engineering program were compared with the mean perceived relative importance findings of the CEAB graduate attributes for all engineering stakeholders to evaluate the content validity of the Biosystems Engineering program.

Research Ethics and University Approval

Ethics approval for the study was granted through the Education and Nursing Research Ethics Board (ENREB) at the University of Manitoba. Additionally, permission to survey the university's faculty and students was approved by the Office of Institutional Analysis, and by the Dean of Engineering. To help minimize possible forms of bias, participation for all stakeholders was optional and confidential, and recruitment was sought following all ENREB and University of Manitoba regulations.

FINDINGS

Table 4 illustrates, for each of the 35 core courses in the Biosystems Engineering program, the percentage of content coverage and course assessments of each applicable graduate attribute based on the professional judgement of the course instructors, expert faculty, and accreditation documents. The bottom rows demonstrate the total percentage of content coverage and total percentage of course assessments for each graduate attribute for the whole program. Total percentages are the total sum that each graduate attribute was taught and assessed for each course, multiplied by 100 and divided by 3500 (i.e., 35 courses multiplied by 100% each).

The total core course content taught in the BIOE program comprises just under 50% *Knowledge Base for Engineering*, 13% *Problem Analysis*, just over 10% *Design* and 7% *Communication Skills*, approximately 4.5% each of *Use of Engineering Tools* and *Investigation*, 4% *Impact of Engineering on Society & the Environment*, and just over 1% each of *Individual & Teamwork*, *Professionalism, Ethics & Equity,* and *Economics & Project Management*. There are very similar percentages for the core course content taught and assessed for each CEAB graduate attribute in the Biosystems Engineering program, with the largest discrepancy being 1.5% (for *Problem Analysis*, which is assessed insignificantly more than it is taught).

With one exception, the ranked order of the CEAB graduate attributes based on the course content coverage and course assessments in the Biosystems Engineering program places the most emphasis on the CEAB graduate attribute 'technical' skills (i.e., *Knowledge Base, Problem Analysis, Investigation, Design,* and *Use of Engineering Tools*), and less emphasis on the 'professional' skills (i.e., *Individual &*

Teamwork, Communication Skills, Professionalism, Impact of Engineering on Society & the Environment, Ethics & Equity, Economics & Project Management, and *Lifelong Learning*), reflecting importance in line with the numerical order of the CEAB graduate attributes. The exceptions include the relatively larger emphasis in the program on professional competency, *Communication Skills*, which is emphasized more than the technical competencies, *Use of Engineering Tools* and *Investigation*.

To evaluate the content validity of the Biosystems Engineering program, the course content and assessment data were compared to the mean relative importance of the graduate attributes data based on the perceptions of all stakeholders (students, faculty and industry) who responded to the relative importance questionnaire (n=207). Findings are shown in Table 5.

In Table 5, we see attributes in which the expected levels (column 2, the relative importance of all stakeholders) and observed levels (columns 3 & 4, the

Table 4. Percentage of course content coverage and course assessments (x, x) for CEAB graduate attributes in Biosystems Engineering core program (N=35 courses).

Course Code	CEAB Graduate Attribute											
	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL
CHEM 1300	100,100											
COMP 1012	100,100											
ENG 1460	25,25	50,50			25,25							
MATH 1510	100,100											
PHYS 1050	100,100											
ENG 1430		5,4.5	5,2	40,33		20,11	15,21	8,12	2,3		3,14	2,0
ENG 1440	35,25	60,70	5,5									
ENG 1450	30,35	30,35	2,5	10,10	15,10	5,5	2,0		2,0		2,0	2,0
Written Requirement							100,10					
MATH 1210	100,100											
MATH 1710	100,100											
BIOE 2590	100,100											
BIOE 2900	29,25			31,45		1,5	21,20	4,2.5		4,2.5		10,0
CHEM 1310	100,100											
MBIO 1220	100,100											
BIOE 2480									100,100			
ENG 2022	20,20			50,55	20,20		10,5					
MATH 2132	100,100											
STAT 2220	100,100											
BIOE 2110	50,30	50,70										
BIOE 2790	35,34	60,58	5,8									
MATH 2130	100,100											
BIOE 2800	90,90	10,10										
MECH 2150	20,20	58,58		5,5	17,17							
BIOE 3400				85,91								15,9
BIOE 3590	65,50	10,20	25,30									
BIOE 3900				75,75	10,10		10,10				5,5	
BIOE 3270	40,30	30,40			25,20			5,10				
BIOE 3320	45,45		45,50									10,5
MECH 3482	25,40	40,40	10,10		25,10							
CIVL 4460*						7.5,2.5	7.5,2.5	15,15	35,40	35,40		
BIOE 4900				46,31	5,10	4,7.5	30,29	9,3		0,1.5	3,9	3,9
BIOE 4240			40,42			5,7.5	45,41			5,2.5		5,5
BIOE 4950				31,33	23,10	4,6	23,29	4,2	4,1	0,1	4,5	7,13
ENG 3000		50,50	25,25								25,25	
Total % content in the program	48.8	12.9	4.6	10.7	4.7	1.3	7.5	1.3	4.1	1.3	1.2	1.5
Total % assessment in program	47.7	14.4	5.1	10.8	3.8	1.3	7.3	1.3	4.1	1.4	1.7	1.2
CEAB Graduate Attributes	KB	PA	IN	DE	ET	IT	CS	PR	IE	EE	EP	LL

Note. 1. KB=Knowledge Base for Engineering; PA=Problem Analysis; IN=Investigation; DE=Design; ET=Use of Engineering Tools; IT=Individual and Teamwork; CS=Communication Skills; PR=Professionalism; IE=Impact of Engineering; EE=Ethics and Equity; EP=Economics and Project Management; LL=Lifelong Learning. 2. Course titles are listed in Appendix A. 3. Blank cells = zero. Each horizontal line totals 100%. 4. Students can take CIVL 4460 or ANTH 2430. ANTH 2430 comprises 100% IE for both course content coverage and assessments; whereas CIVL 4460 comprises IT, CS, PR, IE and EE. These data were calculated using the data from CIVL 4460*. 5. See Appendix A: Biosystems Program 5–Year Model for a list of course code descriptions.

Table 5. Comparative view of the mean relative importance of CEAB graduate attributes by all stakeholders with the percentage of course content coverage and assessments in the BIOE program.

CEAB Graduate Attributes	Relative Importance All Stakeholders (n=207*)	BIOE % of Course Content Coverage	BIOE % of Course Assessments
Knowledge Base	9.1%	48.8%	47.7%
Problem Analysis	9.0%	12.9%	14.4%
Investigation	7.2%	4.6%	5.1%
Design	7.0%	10.7%	10.8%
Engineering Tools	8.3%	4.7%	3.8%
Individual & Teamwork	10.9%	1.3%	1.3%
Communication	10.8%	7.5%	7.3%
Professionalism	9.4%	1.3%	1.3%
Impact of Engineering	6.3%	4.1%	4.1%
Ethics & Equity	8.8%	1.3%	1.4%
Econ. & Project Mngt.	6.1%	1.2%	1.7%
Lifelong Learning	7.1%	1.5%	1.2%

Note. Grey areas have similar expected and observed percentages. *Twelve responses were removed from the total responses (N=219) as these participants did not complete the entire questionnaire.

course content coverage and course assessments) are reasonably similar, and others are far apart. Although somewhat arbitrary, the percentages are identical if the highest is no more than twice as much as the lowest. This is because comparisons can be misleading when the range gets narrower, and the relative importance is already relatively narrow. When interpreting the data in this way, we can say that *Problem Analysis, Investigation, Design, Communication Skills, Impact of Engineering on Society & the Environment*, and if we consider only content coverage, *Use of Engineering Tools* have similar expected and observed percentages (highlighted in Table 5). The other six attributes have a larger spread, with *Knowledge Base for Engineering* comprising almost half the Biosystems program (i.e., 48.8% content coverage and 47.7% course assessments), compared to 9.1% mean relative importance attributed by stakeholders. Following this, we see that *Individual & Teamwork*, *Professionalism, Ethics & Equity, Economics & Project Management,* and *Lifelong Learning* have less than 2% emphasis in the Biosystems Engineering program and are given a mean relative importance rating between 6 – 11%. Overall, only *Problem Analysis* and *Design* have higher observed than expected performance; the rest of the graduate attributes have higher expected than observed performance. There is a broader range in the observed performance than in the expected performance.

DISCUSSION

The purpose of this study was to (1) develop a criterion measure of relative importance for each CEAB graduate attribute, and (2) assess the content validity of the Biosystems Engineering program by comparing the expected relative importance to the observed levels of content coverage and assessment, for each graduate attribute.

The graduate attributes, *Problem Analysis, Investigation, Design, Communication Skills, Impact of Engineering on Society & the Environment*, and *Use of Engineering Tools* have similar expected (mean relative importance) and observed (content and assessment coverage in the Biosystems Engineering program) percentages in the data. Generally, the Biosystems Engineering program emphasizes the traditional skills in engineering, followed by the professional skills. In contrast, engineering stakeholders place importance on professional skills, with the most importance placed on *Individual & Teamwork* and *Communication Skills*, the importance that is also reflected in the literature (Bodner 2002; Male 2010; Passow 2012; Passow and Passow 2017).

As expected, the gap between perceived importance and observed coverage was wider for some other graduate attributes. How closely the relative importance compares to what was observed in content coverage and assessment for a particular graduate attribute might have to do with how directly the attribute can be assessed. For most attributes whose percentages were reasonably similar, such as *Problem Analysis, Investigation, Design,* and *Communication Skills*, those attributes can be readily assessed in various forms, including exams, written assignments, presentations, and projects. In contrast, other attributes that showed greater discrepancies between the expected relative importance and observed importance, such as *Professionalism, Ethics & Equity,* and *Lifelong Learning,* tend to be more challenging to assess directly within graded course work (Holsapple et al. 2012; Seniuk Cicek et al. 2016; Shuman et al. 2005).

Knowledge Base was a clear and somewhat surprising exception to this pattern, reflecting the degree to which a graduate attribute can be assessed directly. *Knowledge Base* accounts for almost half the Biosystems Engineering program, which far exceeded stakeholders' perceived importance and previous perceptions (Bodner 2002; Male 2010; Passow 2012; Passow and Passow 2017), except for Nguyen (1998). Logically, many would argue that engineering knowledge is the most fundamental competency of an engineer – indeed, the defining attribute of the profession, as without engineering knowledge, one is not an engineer. So, why then is this not reflected in our relative importance data and the literature? There are at least four possible explanations.

The first possible explanation relates to the methodology used to determine the observed emphasis on graduate attributes in the Biosystems Engineering program. In this study, the estimate of content coverage and assessment on *Knowledge Base* may be higher than it should be. Of the 35 courses, 12 focused entirely (100%) on *Knowledge Base*. Interestingly, 11 of those 12 courses are taught outside the Biosystems Engineering department. As mentioned earlier, the estimated proportion of assessments on each graduate attribute for these externally-taught courses was based solely on the review of the course outline. Based on the graduate attributes that appeared to be covered in the assessments for that course, it was assumed that each attribute was covered equally in terms of content coverage. All 12 courses were lower-year courses (1st and 2nd year). While lower-year courses in disciplines related to engineering (e.g., mathematics, chemistry) tend to focus more on knowledge and less on application and other higher-order objectives compared to upper-year courses, the 100% estimate for the 12 courses in this study may have been an overestimate. It may well be that in several of these 12 courses, there is some attention given to other attributes such as *Problem Analysis, Design* and *Communication Skills*.

A second possible explanation, which relates to the expected level of importance as determined through the survey of stakeholders, is that stakeholders expect that a student graduating from an accredited engineering program will already possess the required level of engineering knowledge. Therefore, stakeholders rely more heavily on the other graduate attributes to separate top engineers. The increased focus on non-technical attributes was noted by Robinson et al. (2005) in their study that explored the most important future competencies for Design engineers. While they emphasized that technical ability remains critically important, a greater focus on other attributes (e.g., personal attributes, project management skills) would help distinguish between satisfactory and outstanding performance more clearly. Thus, it is possible that the expected levels of importance presented in this paper may not be accurate.

A third possible explanation may be that the perceived relative importance of graduate attributes, as determined through the survey of stakeholders, depends on the stage of career focus. We measured the relative importance of the graduate attributes for an EIT at the beginning of their career. We argued that this is when a new engineer first engages with the CEAB graduate attributes in professional practice. We wanted to evaluate how well our program prepared engineers for practice, based on the degree to which each graduate attribute was covered in the program. However, one could argue that we train engineers for competency over their whole career, not just the beginning of their career. Thereby, the measure of an EIT at the beginning of their professional practice may not represent the most accurate portrayal of these attributes in practice. Moreover, we construed importance as the product of frequency and criticality, which stakeholders rated separately for each CEAB graduate attribute. Conceivably, an EIT will be required to use engineering knowledge less frequently at the beginning of their career when they are still in training than an engineer who has been practicing in the field for years, at least individually (i.e., they will be overseen by a senior engineer). Thus, the frequency rating may be lower than expected. Similarly, recalling that criticality was rated in terms of the effect of errors on engineering practice, one can imagine that an EIT would be less likely to work in situations where they can make critical errors. Thus, the criticality rating would be lower. In this scenario, overall, the importance rating of engineering knowledge would be lower than expected for an engineer in practice. Further, when considering the small range in the relative importance data among all 12 graduate attributes (from 6.1% to 10.9%), we know that stakeholders rated each graduate attribute similarly in frequency and criticality. They did not give significantly more weight to one graduate attribute over another, which may be due more to what is expected of a new EIT than a true reflection of the relative importance of the CEAB graduate attributes in engineering practice.

The fourth possible explanation is that CEAB accreditation requires program administrators to report on graduate attribute outcomes and AUs, which are based on the number of hours devoted to engineering fundamentals such as mathematics, natural sciences, engineering science, engineering design, and complementary studies. Other graduate attributes are likely being employed in each of these courses. Still, programs are constrained by CEAB requirements: they must account for a large number of AUs in each of these areas, which naturally leads to a large emphasis on attributes like *Knowledge Base* and the other technical skills in specific courses, and to the reduction of a formal accounting of the attributes that are not counted for AUs, which mainly, in this case, are the professional skills.

Limitations

Perhaps this study's most apparent and inherent limitation was that the results reflect only a single department within a single engineering program. As such, the findings in this study must be regarded with considerable caution.

As noted, several times above, the measures and procedures are pretty novel, both in this study and the field of engineering education. The overall intent of this study was perhaps more methodological than it was topical. We wanted to introduce a newer approach to evaluating how graduate attributes are covered in engineering programs, which can be refined in future efforts. While the measures we developed for this study were well-researched and carefully prepared, we realize, as noted in several places above, there are clear areas for improvement that we can expect to align more closely with the unique contexts in engineering education.

The main focus of this research was to compare the expected level of importance to what is observed in the Biosystems Engineering program (which we have chosen to represent by 'proportion of instruction time' and 'percentage of grade allocation' for each graduate attribute). The data in Table 5 demonstrates that there was a reasonably close match between the expected level of importance (as indicated by the survey of stakeholders) and the proportion of instruction time (or percentage of grade allocation) observed in the Biosystems Engineering program for at least five graduate attributes; however, it also clearly shows that there is not a good match for the others. In the preceding discussion, an effort has been made to explain this discrepancy based primarily on two assumptions: 1) that the relative importance indicated by the stakeholders is correct and 2) that proportion of instruction time (or percentage of grade allocation) are appropriate indicators of the level of emphasis within an engineering program. Each of these assumptions warrants future investigation. Is it true that all 12 graduate attributes have roughly equal importance, or did the survey instrument used in this study fail to consider other factors that may contribute to the 'true' expected level of importance? Likewise, are 'proportion of instruction time' or 'percentage of grade allocation' suitable measures for the emphasis or value placed on a specific graduate attribute by an engineering department? Using the Biosystems Engineering program as an example, we offer one example to suggest that this latter assumption may not be appropriate. Table 5 indicates that less than 2% of total instruction time is devoted to formal instruction on teamwork (or assessment of teamwork skills in the Biosystems Engineering program). While there may be no reason to doubt the accuracy of these two numbers, it is also a known fact that there are five design courses in the Biosystems Engineering program (representing 11% of the entire program) that require term-long team projects, in addition to numerous other courses that have shorter-duration team projects. The Department of Biosystems Engineering emphasizes the importance of this graduate attribute by providing multiple opportunities for students to work in team settings. It does not appear that the metrics of 'proportion of instruction time' or 'percentage of grade allocation' truly reflect the emphasis on the graduate attribute of teamwork in the Biosystems Engineering program. Further research is likely required to investigate other potential metrics to reflect the level of emphasis in an engineering program more accurately.

Recommendations for programs

While the findings of this study may not justify considering course or program changes in engineering, one particular finding is perhaps a bit more deserving of consideration. The Biosystems Engineering program appears to have minimal emphasis on the professional graduate attributes such as *Professionalism*, *Ethics & Equity*, and *Lifelong Learning*, which are rated comparatively higher in relative importance by all engineering stakeholder groups in this case. Engineering educators arguably have a societal responsibility to integrate 'ethical reasoning' into the engineering curriculum (Sheppard et al. 2008) and educate socially responsible engineers (Lathem et al. 2011; Terpenny et al. 2008). Research has shown that engineering practice is, by necessity, both social and technical (Cohen et al. 2014; Faulkner 2007; McGowan and Bell 2020). Practicing engineers must identify and integrate the social and technical elements of open-ended problems and evaluate their impact (Stevens et al. 2014; Swartz et al. 2019; Trevelyan 2014).

For this reason, engineering accreditation boards, including CEAB, require university programs to demonstrate that engineering students understand the social dimensions and consequences of engineering practice (Engineers Canada 2019). This has been defined as sociotechnical thinking (Hoople and Choi-Fitzpatrick 2020; Leydens et al. 2018; Mazzurco and Daniel 2020), which is a critical skill for engineers due to the sociotechnical nature of engineering practice. Thus, there is good reason for department administrators to actively pursue opportunities to further emphasize the professional graduate attributes, potentially by integrating the teaching of professional skills with the teaching of technical skills to avoid de-emphasizing one set of graduate attributes to emphasize another.

Recommendations for future research

Recommendations for future research focus on evaluating course content and assessments more accurately and making more meaningful comparisons between expected and observed coverage for each CEAB graduate attribute. To help improve the accuracy of measuring content coverage and assessments within a course, those should be measured directly, when possible, by asking all instructors to rate the proportion of course content coverage for each applicable attribute (i.e., in this study, the 14 (of 35) courses offered either within the Price Faculty of Engineering or in the Faculties of Arts or Sciences – where faculty did not fill out the questionnaire). For assessments, copies of blank assessments or sufficiently detailed descriptions should be obtained.

Another recommendation is to compare the relative importance ratings to the course content coverage and course assessments in the 3rd and 4th years of the program only. If the relative importance ratings are based on visualizing someone in the field who is expected to apply all 12 attributes, it might make more sense to compare the relative importance to the part of the program where students are expected to apply most/all of the 12 graduate attributes, rather than comparing the relative importance to the part of the program that is logically expected to strongly emphasize only one of the 12 attributes (i.e., *Knowledge Base*).

Finally, it is recommended that a qualitative investigation of the findings be conducted. For example, focus groups could be held with stakeholder groups to explore their understandings of the similarities and discrepancies between the expected levels of importance and the observed levels of performance of the graduate attributes in the Biosystems Engineering program. This will help us understand these findings more.

CONCLUSION

This study was the first among engineering programs in Canada to measure the variation in the level of importance of the CEAB graduate attributes and compare that against the content coverage and assessment of those attributes within an engineering program. Some of our findings emerged as expected in the sense that the relative importance was not too far away from the amount of content coverage and assessments for several graduate attributes (e.g., *Design*, *Investigation*). Other findings were less clear and somewhat surprising (i.e., the distance between the expected and observed performance of *Knowledge Base*). We offer that one of the main contributions of this study is the practical and relevant directions to improve the validity of assessing the CEAB graduate attributes. As far as course and program considerations, we suggest that the professional engineering competencies, including *Professionalism, Ethics & Equity,* and *Lifelong Learning*, which are emphasized in relative importance in this study and the literature, be further emphasized in the Biosystems Engineering curriculum to ensure that students develop socio-technical thinking. Further research to improve the teaching and assessments of the professional graduate attributes is proving to be increasingly critical for the preparation of engineering students for professional practice.

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LIST OF SYMBOLS

ABET	Accreditation Board for Engineering and Technology
AU	Accreditation Unit
CEAB	Canadian Engineering Accreditation Board
EIT	Engineer-in-training
ENREB	Education and Nursing Research Ethics Board
NEERC	National Engineering Education Research Colloquies

APPENDICES

Appendix A: Biosystems Program 5–Year Model

Year 1	
1	*Complementary Studies Elective 1*
2	CHEM 1300 Structure and Modelling in Chemistry
3	COMP 1012 Computer Programming for Science and Engineers
4	ENG 1460 Introduction to Thermal Sciences
5	MATH 1510 Applied Calculus 1
6	PHYS 1050 Physics 1: Mechanics
7	ENG 1430 Design in Engineering
8	ENG 1440 Introduction to Statics
9	ENG 1450 Introduction to Electrical and Computer Engineering
10	Written Requirement
11	MATH 1210 Techniques of Classical and Linear Algebra
12	MATH 1710 Applied Calculus 2
Year 2	
13	BIOE 2590 Biology for Engineers
14	BIOE 2900 Biosystems Engineering Design 1
15	CHEM 1310 University Chemistry 1
16	MBIO 1220 Essentials of Microbiology
17	BIOE 2480 Impact of Engineering on the Environment
18	ENG 2022 Engineering CAD Technologies for Biosystems
19	MATH 2132 Engineering Mathematical Analysis 2
20	STAT 2220 Contemporary Statistics for Engineers
21	*Complementary Studies Elective 2*
Year 3	
22	BIOE 2110 Transport Phenomenon
23	BIOE 2790 Fluid Mechanics
24	MATH 2130 Engineering Mathematical Analysis 1
25	*Science Elective 1 (BIOL 1410 or SOIL 4060)*
26	BIOE 2800 Solid Mechanics
27	MECH 2150 Mechanical Engineering Modeling and Numerical Methods
28	*Science Elective 2 (BIOL 1412 or BIOE 2600) Elective Slot*
Year 4	
29	BIOE 3400 Design of Structural Components in Machines
30	BIOE 3590 Mechanics of Materials in Biosystems
31	BIOE 3900 Biosystems Engineering Design 2
32	*Complementary Studies Elective 3*
33	BIOE 3270 Instrumentation and Measurement for Biosystems
34	BIOE 3320 Engineering Properties of Biological Materials
35	MECH 3482 Kinematics and Dynamics
36	ANTH 2430 Ecology, Technology and Society (or CIVL 4460 Technology, Society & the Future)
37	*BIOE Design Elective 1*
Year 5	
38	BIOE 4900 Biosystems Engineering Design 3
39	BIOE 4240 Graduation Project
40	*BIOE Design Elective 2*
41	*Free Elective 1*
42	BIOE 4950 Biosystems Engineering Design 4
43	ENG 3000 Engineering Economics
44	*BIOE Design Elective 3*
45	*Free Elective 2*

Appendix B: CEAB Graduate Attributes Rating Form

	CEAB Graduate Attributes	Frequency	Criticality
1	**A knowledge base for engineering**: Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.		
2	**Problem analysis**: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.		
3	**Investigation**: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data and synthesis of information in order to reach valid conclusions.		
4	**Design**: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.		
5	**Use of engineering tools**: An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		
6	**Individual and team work**: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.		
7	**Communication skills**: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.		
8	**Professionalism**: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.		
9	**Impact of engineering on society and the environment**: An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of sustainable design and development and environmental stewardship.		
10	**Ethics and equity**: An ability to apply professional ethics, accountability, and equity.		
11	**Economics and project management**: An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering and to understand their limitations.		
12	**Lifelong learning**: An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.		

Appendix C: **Teaching Faculty Course Content Questionnaire**

Example for BIOE 2790. (*Note:* Questionnaire was created for each individual course in the program, based on the graduate attributes that were identified for accreditation purposes.)

Teaching Faculty Course Content Questionnaire

1. Based on the Graduate Attribute table that was developed for BIOE 2790, these CEAB graduate attributes are taught and/or assessed in your course:

Graduate Attribute	Weight	Level I/D/A
A Knowledge Base for Engineering		I
Problem Analysis		I
Investigation		I

Is the list correct? Yes ______ No ______

(If no, please cross out any graduate attributes that are listed but aren't associated with your course and/or add any graduate attributes that are missing.)

2. In your judgment, when you consider the content covered in this course (i.e., through teaching, readings, homework, and other methods of course content delivery), approximately what percentage of the content is allocated for each of the graduate attributes listed in question 1?

Graduate Attribute	Percentage of content coverage (where total does not exceed 100%)
Total:	</= 100%

3. In your judgment, when you consider all of the assessment tools used in this course (i.e., any work that students will receive a mark/grade for, including lab reports, homework, tutorials, quizzes, tests, exams, projects, etc.), approximately what percentage of these assessments is allotted to each of the graduate attributes listed in question 1?

Graduate Attribute	Percentage of assessments (where total does not exceed 100%)
Total:	</= 100%