INTERNATIONAL EXPECTATIONS OF ENGINEERING GRADUATE ATTRIBUTES

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ABSTRACT

As societal and organizational dynamics change, the skills expected from graduating engineers also change. Regulating bodies worldwide mandate and update these expectations with engineering graduate attributes or competency guidelines. These regulations direct engineering education institutions towards the expected outcomes of the engineering curriculum. The goal of this study is to determine internationally-common skill requirements of graduating engineers. Graduate attribute guidelines from 17 worldwide engineering regulating bodies were collected. The data was analyzed using content analysis in order to reduce the data down into main themes. Five overall themes of engineering graduate attributes were identified: knowledge base, professionalism, problem solving, diverse work setting, and design. These five themes were split into 21 categories, and of these categories, five were essential as they were included in all of the countries analyzed. Comparing the categories with the CDIO Syllabus showed a high level of correlation indicating that international accreditation bodies are using similar attributes as those outlined within the CDIO Syllabus. The areas with no correlation provide the basis for improvement within both the graduate attributes and the CDIO Syllabus.

KEYWORDS

Graduate Attributes, Washington Accord, Qualitative Content Analysis, CDIO Syllabus, Standards: 2,3

INTRODUCTION

The increased impact that technology has had on our daily lives over the last few decades (Brynjolfsson & McAfee, 2014) has placed the engineering profession in a position of growing importance, and with this has come increased responsibility. Given the extent to which engineering achievements can potentially influence social, economic and environmental systems, both the engineering profession and the process by which engineers are educated are now at the forefront of national and international agendas (NAE, 2007; Seeley, 1999). As an early example, a 1984 keynote address presented by US Engineer Bernard Gordon

(Gordon, 1984) to the European Society for Engineering Education (SEFI) stressed the importance of teaching engineering students not only technical knowledge, but also the attitudes and skills required to perform as a professional engineer. Gordon also discussed how advances in technology would require the engineering curriculum to become "internationalized," going so far as to say that local standards, if left in isolation, would be doomed to fail.

Over the decades since these early observations by Gordon, others have raised similar concerns, stressing the importance for engineering education programs to offer a more holistic and well-rounded curriculum (Goldberg & Sommerville, 2014; McKenna, Froyd, & Litzinger, 2014; McMasters, 2004). Combining the international perspective specified by Gordon (1984) with the recognition that engineering education needs to be more than only the infusion of technical knowledge (the *liberal arts degree of the 21st century*, as McMasters (2004) imagined), the International Engineering Alliance (IEA) set out to specify a shared list of engineering graduate attributes that could be applied across nations. Signatories of the IEA's Washington Accord would then be able to use these engineering graduate attributes to develop outcomes-based accreditation criteria to suit their own jurisdictions (IEA, 2014). With these criteria, a mechanism for international collaboration, global mobility, and improved unity in the increasingly diverse workplace could be created. While a common root exists within the IEA's graduate attributes, signatories would also have a degree of freedom to customize the graduate attributes so as to account for variability in the situational context.

The question then follows: what are the common attributes expected of engineering graduates that have evolved through this multi-nation process? This paper attempts to answer this question by first starting with the graduate attributes as specified by each of the signatories of the Washington Accord and then applying content analysis using the constant comparative method. Through this process, common themes and categories of attributes are determined. Proportional frequency analysis of the data gives insight into the degree to which these attributes have been adopted internationally.

BACKGROUND

Graduate Attribute (GA) Development

Accreditation criteria for the evaluation of engineering programs have been discussed for decades, and the introduction of formal graduate attributes reached a milestone in 1996 with the document the "Desired Attributes of an Engineer" (Boeing, 1996). Since the beginning of the 21st century, graduates from engineering programs have been expected to have a specific set of skills indicative of an appropriate level of practice (IEA, 2014), referred to as graduate attributes. Graduate attributes (GAs) are also called competency guidelines or programme outcomes. These attributes are mandated, regulated and updated by national accreditation bodies, and they direct institutions towards the expected outcomes for their respective engineering curricula.

Outcomes-based education has been a strong catalyst for curricular change and improvement in engineering education (Maranville, O'Neill, & Plumb, 2011). The structure provided by the GAs facilitates the transformation process and provides a systematic method to the development of curriculum. Considering that universities closely follow the accreditation requirements, it is important to understand if the GAs are appropriate and consistent. This paper seeks to investigate international consistency through the comparison of the GAs provided by the organizations affiliated with the Washington Accord.

Washington Accord

In 1989, the International Engineering Alliance signed the Washington Accord, an international agreement among national accreditation bodies from six countries: the UK, Ireland, USA, Canada, Australia, and New Zealand (IEA, 2014). The Washington Accord recognizes that the "accreditation of engineering academic programs is a key foundation for the practice of engineering at the professional level" (Hanrahan, 2011). By internationally recognizing accredited institutions, *substantial equivalence* can occur, a process where two programs in different countries are considered to be equally acceptable in preparing their graduates for international engineering work (Hanrahan, 2011). Currently there are 17 countries that have signed the Washington Accord, with the signatories indicated in light blue in Figure 1.

Figure 1. Current Washington Accord Signatory Countries.

METHOD

Qualitative content analysis methods were used for the purpose of this study. This methodology was chosen to answer the following research question: *what are the common attributes expected internationally from engineering graduates?* It provided a method to examine the many definitions of graduate attributes and to produce an overall understanding of international expectations, or “sense making” as defined by Paton (cited in (Zhang & Wildemuth, 2009)). Qualitative content analysis typically involves purposefully selecting the data in order to answer a research question, aiming to examine the themes within the data and produce descriptions of how the data views the social world (Zhang & Wildemuth, 2009).

The definitions of GAs were taken from countries worldwide based on the 17 national organizations accredited by the Washington Accord. The data from each of the 17 organizations were collected by visiting the links provided on the Washington Accord website (IEA, 2014). The Washington Accord signatories were chosen due to the completeness of their GAs definition, the ability to find documentation in English, and the relatively strong equivalence in the countries development status and technological ability.

Once the data was collected, the three phases of qualitative content analysis were followed: preparing, organizing and reporting (Elo & Kyngäs, 2008). During the preparation phase, it was important to define the unit of analysis in order to consistently code the data. The unit of analysis was defined as a “single concept,” typically including a verb / a subject / and the context.

Next, during the organizing phase, the GAs were coded using the provided unit of analysis. Examples include “design / a process / to meet needs,” “meet / the needs / of society,” and “apply / relevant analytical methods / to problems”. Each of the 17 countries’ GAs were coded, and the entire set of codes (704 total, 22-69 for each country) was compiled. Similar codes were grouped into headings, then reduced into five main themes, and lastly abstracted to generate 21 categories and 28 sub-categories. Finally, the reporting phase examined and summarized the findings.

Throughout the coding process, questions from the method of constant comparative analysis were used. Each code was determined by asking, “What is this data a study of? What category does this incident indicate? What is actually happening in the data?” (Glaser, 1978, p. 57). These questions guided the coding process in order to ensure the continuous comparing and contrasting of the data, codes, themes, and categories.

FINDINGS AND DISCUSIONS

A summary of the GA data collected can be seen below in Table 1. The number of criteria and words within each GA definition provides information on the relative length of each document. The longest GA list was provided by the United Kingdom with 33 criteria and 433 words. The shortest was provided by Taiwan with eight criteria and 98 words (although Ireland had less criteria with only six, it was 113 words in length). It is important to mention that some organizations had multiple levels of detail for defining their GAs. When this was the case, the lowest level of detail was collected for the purpose of this study.

Similarities were observed between some countries' GAs. The Washington Accord itself defined a list of GAs, and this definition was used almost verbatim by four countries (India, Malaysia, New Zealand, and Sri Lanka). As well, Hong Kong and the United States had strong similarities between their lists of GAs. Each country was still viewed independently for the analysis, but the impact of these duplications was taken into consideration.

Table 1. Summary of the graduate attribute (GA) data from the 17 countries, obtained through the Washington Accord signatory links (IEA, 2014)

Country	**Represented by**	**Year of Signing**	**# of Criteria (# of words)**
Australia	Engineers Australia	1989	16 (162)
Canada	Engineers Canada	1989	12 (347)
Hong Kong	The Hong Kong Institution of Engineers	1995	12 (180)
India	National Board of Accreditation	2014	12 (422)
Ireland	Engineers Ireland	1989	6 (113)
Japan	Japan Accreditation Board for Engineering Education	2005	9 (99)
Korea	Accreditation Board for Engineering Education of Korea	2007	12 (132)
Malaysia	Board of Engineers Malaysia	2009	12 (227)
New Zealand	Institution of Professional Engineers NZ	1989	11 (333)
Russia	Association of Engineering Education of Russia	2012	14 (231)
Singapore	Institution of Engineers Singapore	2006	10 (135)
South Africa	Engineering Council of South Africa	1999	10 (203)
Sri Lanka	Institution of Engineers Sri Lanka	2014	12 (325)
Taiwan (Chinese Taipei)	Institute of Engineering Education Taiwan	2007	8 (98)
Turkey	MUDEK	2011	11 (261)
United Kingdom	Engineering Council UK	1989	33 (433)
United States	ABET	1989	11 (135)

Global Graduate Attribute (GA) Themes and Categories

Using the qualitative content analysis method, five themes were derived from the data: knowledge base, professionalism, problem solving, diverse work setting, and design. Each of these five themes was broken down into categories, for a total of 21, as seen in Figure 2 (the additional 28 sub-categories can be seen in Table A1 in the Appendix). The five themes generated represent the main areas of engineering attributes regulated by national bodies. These could be useful for universities when performing a high-level curriculum review as it provides a starting point of five broad areas to consider.

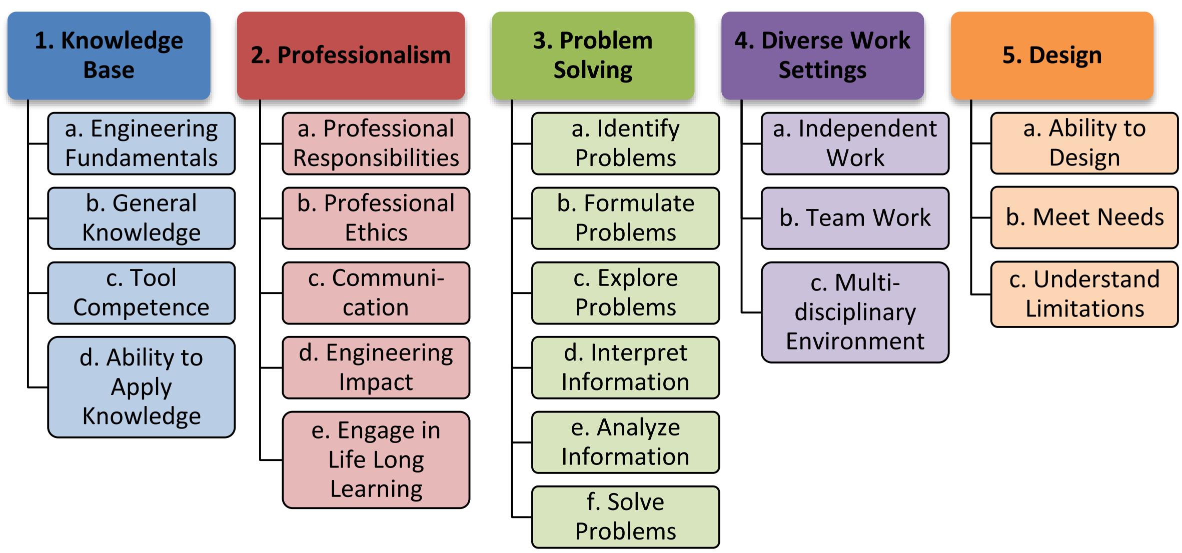

Figure 2. Themes & categories generated from 17 countries' graduate attributes.

Proportional Frequency of Graduate Attribute (GA) Categories

The proportional frequency analysis provides an understanding of how many countries included each of the categories. Figure 3 shows a visual representation of the proportional frequencies. Five of the 21 categories (or 32% of the codes) were included in all 17 of the countries' GAs. Another six categories (or 31% of the codes) were almost always included, being mentioned by 16 of the countries. The two categories with the lowest inclusion rates were *4a. Independent Work* and *5b. Meet Needs*, included by only 12 of the 17 countries.

The five categories in Figure 3 that were included in all 17 organizations represent the global consensus of essential attributes for a graduating engineer. These five categories represent a significant portion of the entire engineering curriculum and should be embedded throughout any engineering program, and were highlighted in grey in Figure 3. However the remaining categories are also critically important. National accreditation bodies which have not included the remaining categories should investigate whether adding them would be beneficial to their engineering education programs.

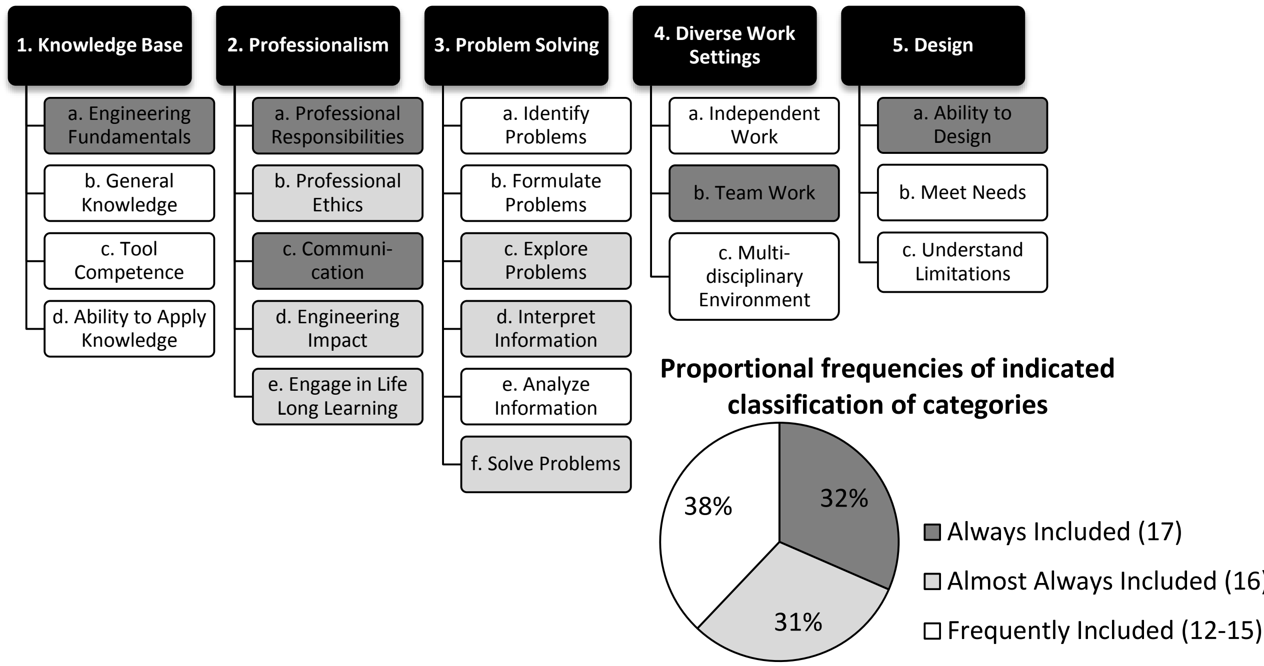

Figure 3. The proportional frequencies of the categories based on the number of countries in which each category was mentioned.

The degree to which each of the above categories is embedded within engineering curriculums in practice is often minimal (Litzinger et al., 2011), particularly those included in the themes *Professionalism, Diverse Work Settings,* and *Design.* Many of these attributes are only addressed in one or two courses during a students' entire postsecondary education, typically in a "catch all" first or final year design course (Neumeyer, Chen, & McKenna, 2013). Yet, research has shown that the integration of content across the curriculum allows students to retain more skills, develop deeper expertise, and integrate their knowledge to solve complex problems, as well as attain higher retention rates and improve student motivation (Karim et al., 2012; Litzinger et al., 2011; Martello & Stolk, 2007).

CDIO Standard 3 Integrated Curriculum encourages this, stating that there should be "an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills" (Crawley, Malmqvist, Östlund, Brodeur, & Edström 2014, p. 36). It would be recommended for national accreditation bodies to consider including a requirement for the integration of professional attributes within the technical curriculum content. One of the best approaches to improving the integration of content is to provide instructors with training that gives them the ability to embed the professional attributes within their technical course content (Teerijoki & Murdoch, 2014; CDIO Standards 9 and 10).

Comparison of the Findings with the CDIO Syllabus

The findings from this analysis were compared with the CDIO Syllabus in order to determine the correlation between countries' GAs and the Syllabus. Each GA category was compared with the subsets of the CDIO Syllabus (second level of detail). If a Syllabus subset was unclear, the third level of detail was referenced for contextual understanding.

The correlation table (Table 2) highlights similarities and differences between the generated GA categories and the CDIO Syllabus. An example of a strong correlation would be *GA 2a. Professional Responsibility* and *CDIO 2.5 Ethics, Equity and Other Responsibilities.* These two categories are very similar and would be viewed as analogous. An example of a weak correlation would be *GA 3e. Analyze Information* and *CDIO 2.1 Analytical Reasoning and Problem Solving*. Although these two categories have some similarity, there is a slightly different meaning between analyzing information and analytical reasoning.

The one CDIO Syllabus subset that was not represented in the GA categories was *4.6 Operating,* the fourth and final phase of the innovation process. The Syllabus defines *Operating* as an understanding of operations, the lifecycle and evolution of systems, including abandonment or end-of-service issues. The operation phase of the CDIO Syllabus particularly emphasizes an understanding of the lifecycle with a sustainability perspective (Crawley et al., 2014). If the International Engineering Alliance decides to revise the documents surrounding the Washington Accord, it may be beneficial to consider including attributes surrounding *Operation*.

There were also two CDIO subsets that were only weakly represented in the GA categories, *3.3 Communication in Foreign Languages,* and *4.5 Implementing,* the third phase of the innovation process. Looking at Table 2, it is evident that there are more "High Correlation" points on the left side of the table, and fewer on the right. As part 4 of the CDIO Syllabus covers the innovation process, this suggests that the GAs lack components of the innovation process.

All of the categories generated from the GAs were represented in the CDIO Syllabus. This is indicative of the attention to detail provided by the CDIO Syllabus. However, there were four GA categories only weakly represented: *1d. Ability to Apply Knowledge; 3e. Analyze Information; 4c. Multidisciplinary Environment; and 5c. Understand Limitations.* Each of these categories were not represented in the second level of detail of the CDIO Syllabus but rather were seen within the third level of detail. Based on the literature examined, the one area that perhaps should be addressed at a higher level in the CDIO Syllabus is *3.1.5 Multidisciplinary Teaming*. The modern engineering environment is often multidisciplinary, and thus the required collaborative and social skills need to reflect this. The importance of these skills emphasizes the need to include them within the engineering curriculum Ashton, Bailey, Coomber, Goodell, & Weiland, 2012; Huet et al., 2008).

Table 2. Correlation of the GA categories and the CDIO syllabus subsets.

	CDIO Syllabus																
Graduate Attributes	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3*	4.1	4.2	4.3	4.4	4.5*	4.6**
1a. Eng. Fundamentals	**X**	**X**	**X**														
1b. General Knowledge												X	**X**				
1c. Tool Competence			**X**													X	
1d. Apply Knowledge*															X		
2a. Professional Resp.								**X**				X					
2b. Professional Ethics								**X**									
2c. Communication										**X**	X						
2d. Engineering Impact												**X**					
2e. Engage in LLL							**X**	X							X		
3a. Identify Problems				**X**													
3b. Formulate Problem				**X**	X												
3c. Explore Problems					**X**	X											
3d. Interpret Info.						**X**								X		X	
3e. Analyze Info.*				X													
3f. Solve Problems				**X**													
4a. Independent Work							**X**										
4b. Team Work									**X**								
4c. Multidisciplinary*								X	X						X		
5a. Ability to Design														X	**X**	X	
5b. Meet Needs												**X**		**X**	X		
5c. Know Limitations*						X						X					

X	Strong Correlation	*These CDIO and GA categories represent analogous skills, with very similar wording.*
X	Weak Correlation	*These CDIO and GA categories represent similar skills with slightly different meanings.*
*	Weakly Represented	*These CDIO or GA categories have only weak representation in the other.*
**	Not Represented	*These CDIO or GA categories do not have any representation in the other.*

RECOMMENDATIONS FROM THE FINDINGS

Based on the findings and discussions, the following recommendations are made.

1. GAs, particularly the professional skills, should be integrated and embedded in engineering education. Universities should interpret subsets of the graduate attributes as requirements for *each* course, rather than a requirement to be satisfied only once or twice during the overall curriculum delivery.

    a. For new curricular development a recommended starting point would be to integrate two or more of the essential categories (engineering fundamentals,

professional responsibilities, communication, teamwork, and ability to design) within as many courses as possible.
   b. Regulatory bodies could include the integration of the attributes throughout the curriculum as a requirement of their accreditation process.

2. The majority of the GAs are linked to the conceive-design phases of the innovation process. It is recommended that accreditation bodies consider adding attributes to ensure students are able to conceptualize the full lifecycle (implement-operate), particularly in terms of operation and sustainability.

3. The CDIO syllabus is extremely comprehensive and thorough. The one area for improvement that is recommended would be to include a larger degree of emphasis on multidisciplinary experiences within engineering education.

CONCLUSION

Overall, the results provide insight into the commonalities and highest priorities within the graduate attributes chosen by the Washington Accord signatories. The five essential categories (included in all 17 organizations) provide the most significant correlation. These are five specific categories that, worldwide, are crucial attributes for graduating engineers. The high level of correlation between Washington Accord signatories and the CDIO Syllabus indicates that international accreditation bodies are using similar attributes. The areas where limited or no correlation exists provide suggestions for improvement.

LIMITATIONS AND FUTURE RESEARCH

All of the data was obtained from countries accredited by the International Engineering Alliance, and thus it was expected that there would be a certain level of consistency across the data. However, insight was gained into the most essential attributes and the attributes that are most highly emphasized. If a future study were to look at the graduate attributes across a wider range of countries, including those that are not signatories of the Washington Accord, it would be informative to learn whether the analysis provides different results.

Within the curriculum, the graduate attributes are taught through a variety of teaching and learning activities (TLAs). With an improved understanding of the international expectations of engineering graduate attributes, the next step is to determine how institutions develop, assess, and track these attributes in undergraduate engineering students. Further research summarizing the varied TLAs being used will seek to identify the best practices that assist in the process of continuous program improvement. Engineering graduate attributes for which there appears to be an insufficient number of TLAs reported in the literature will also suggest paths for future research.

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APPENDIX

Table A1. Themes, categories and sub-categories determined from the graduate attributes.

THEMES	CATEGORIES	SUB-CATEGORIES
Knowledge Base	Engineering Fundamentals	
	General Knowledge	Business Practices
		Contemporary
		Sustainability
	Tool Competence	Create Tools
		Understand Techniques
	Ability to Apply Knowledge	Apply Knowledge
		Apply Methods
		Apply Skills
Professionalism	Professional Responsibilities	
	Professional Ethics	
	Communication	Oral Communication
		Communicate with Others
		Written Communication
	Engineering Impact	
	Engage in Life Long Learning	Independent LLL
		Recognize Need for LLL
Problem Solving	Identify Problems	
	Formulate Problems	
	Explore Problems	Experimentation
		Investigation
		Research
	Interpret Information	Synthesis of Information
	Analyze Information	Data Analysis
		Problem Analysis
	Solve Problems	Determine Solution
Diverse Work Settings	Independent Work	Adaptability
		Creativity
		Self Management
	Team Work	Leadership
		Project Work
	Multidisciplinary Environment	
Design	Ability to Design	Design Components
		Design Experiments
		Design Processes
		Design Systems
	Meet Needs	
	Understand Limitations	

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