Proceedings of The Canadian Society for Mechanical Engineering International Congress 2018
CSME International Congress 2018
May 27-30, 2018, Toronto, On, Canada

GRADUATE ATTRIBUTES AND THRESHOLD CONCEPTS: ARE WE MEASURING WHAT'S IMPORTANT?

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Abstract**—** A great deal of work has been done within the engineering community to identify the threshold concepts that students must master in order to transform from novice to practitioner. At the same time, engineering regulatory bodies have established a set of graduate attributes that help ensure graduating engineers are prepared to practice professional engineering. Students and recent graduates have identified that one area in which they felt lacking in skills and confidence was solving the complex and multi-faceted problems encountered in the engineering work place. This seems to indicate that students have not fully mastered one or more discipline-specific threshold concepts. This paper presents a framework engineering educators can use to identify, map, and monitor those concepts as key indicators used to track graduate attributes.

Keywords: threshold concepts; graduate attributes; engineering education; key indicators; benchmarks

I. INTRODUCTION

Engineers Canada reports that 69,015 undergraduate engineering degrees were conferred over the five year span from 2012 to 2016 [1]. This trend is expected to continue as the overall number of enrolments increases yearly. But are these graduates confident that they can apply their acquired knowledge and skills in the workplace?

Engineering education research has identified a number of threshold concepts that learners must master as they make their way from novice to practicing engineer. At the same time, engineering accrediting bodies, including the Canadian Engineering Accreditation Board (CEAB), have identified a set of graduate attributes to ensure graduates are prepared for a professional career. Each accredited engineering program is responsible for identifying and monitoring a set of benchmarks or key indicators for each of these graduate attributes.

This paper discusses the pilot test of a mapping framework used to determine the relationship between existing key indicators and established threshold concepts. This information can help shape the continual improvement process as programs work to strengthen the undergraduate engineering experience.

II. BACKGROUND

A. *Engineering Education*

Over the last 100 years engineering education has shifted from a hands-on practical approach to one that focuses on engineering science and analysis [2][3]. Currently there are moves toward outcomes-based curriculum, increased design experience in the undergraduate curriculum, and educating "engineers who can engineer" [4]. There are currently 43 schools offering 281 different accredited engineering programs in Canada. These programs range from the more traditional offerings of civil, mechanical, and electrical engineering, to disciplines as varied as aerospace, biomedical, environmental, sustainable design, petroleum, and software engineering [5].

Canadian engineering schools have been accredited since 1965. This process ensures that graduates of engineering programs meet the high standards necessary to become professional engineers. An accreditation review examines the depth and breadth of the science, mathematics, engineering science, engineering design, and complementary studies curriculum, as well as 12 graduate attributes that ensure proficiency in discipline-specific knowledge and skills, employability skills, and professional responsibility [6].

B. *Graduate Attributes*

All graduating engineers must be technically competent. They must have mathematical, scientific, and discipline-specific knowledge, and be able to analyze and solve complex engineering problems. They must know how to conduct investigations in order reach valid conclusions. They must be able to design solutions and systems for open-ended problems, and use engineering tools appropriately. This professional body of knowledge forms the core of every engineering program.

Graduate attributes move beyond these technical abilities to include a set of qualities required of graduates as they become practicing engineers. In order to be employable graduates must be able to work both individually and as part of a team. They must be able to communicate effectively and continue to learn throughout their careers. Most importantly, engineers must be able to make professional, responsible, and ethical decisions for which they are accountable. The challenge for engineering programs is to choose appropriate indicators that demonstrate their students are meeting each of these graduate attributes.

C. *Threshold Concepts and Threshold Practices*

Long before Meyer and Land coined the term 'threshold concept' [7], educators were questioning whether students actually understood what was being taught in a class [8][9], and looking for ways to help overcome common bottlenecks in student learning[10].

Meyer and Land defined a threshold concept as a portal, a way of thinking about something in a "new and previously inaccessible way"[7]. They considered it a space between where a learner is and where that learner needs to be in order to make the transition from novice to experienced practitioner in a discipline. Some learners master threshold concepts quite easily, while others struggle in a transitional state called liminality. With new knowledge to learn and misconceptions and misunderstandings to unlearn, this liminal state can involve disorientation and ambiguity as a learner moves between a state of knowing and not knowing.

A threshold concept is identified by five key characteristics: it is (1) transformative, (2) troublesome, (3) irreversible, (4) integrative, and (5) bounded. Land nicely summarizes these in a 2013 interview for Tomorrow's Professor Newsletter [11]:

"New conceptual understandings pull together (integrate) various stands of understanding into a new understanding that fundamentally changes (transforms) the way students think about the subject. Because the process involves the loss of a familiar way of thinking and the security it provides, the process of crossing the threshold commonly causes some mental and emotional discomfort (troublesome). There's some debate about whether these new understandings are reversible or not, but once a student "gets it," it seems hard for them to "un-get it." "Bounded" seems the least obvious descriptor perhaps because its meaning derives more from contextual concerns than specifically conceptual ones."

Over the years, the definition of a threshold concept has expanded to include threshold skills and practices [12][13]. Like a threshold concept, a threshold skill is considered to be transformative, integrative, and troublesome. It is, however, considered only semi-irreversible, since learners tend to lose certain skills if they are not practiced, practice being the fifth characteristic. The idea of partial understanding exists for threshold concepts, where a learner can apply the concept, but not explain it in an abstract way. With threshold skills this is considered partial mastery where a learner can only demonstrate certain parts of the skill or practice, or knows that the skill should be used, but cannot to use it properly.

D. *Threshold Concepts in Engineering*

Much work has been done to identify threshold concepts within specific engineering disciplines, but a research study out of the University of Western Australia created the first Integrated Engineering Threshold Concept Inventory (IETCI) [13]. These concepts, which include a number of graduate attributes, are grouped into three main categories: (1) learning to become an engineer, (2) thinking and understanding like an engineer, and (3) shaping the world as an engineer.

Funded by National Sciences and Engineering Research Council of Canada (NSERC)

Learning to become an engineer includes recognizing the role an engineer plays in society, the values and responsibilities associated with being an engineer, and the engagement in and responsibility for one's own learning. It also includes the thresholds associated with teamwork and communicating. Thinking and understanding like an engineer encompasses the abstraction, modeling, and theories required to master the core concepts within one's discipline, and shaping the world as an engineer includes engineering design, and the approaches, thinking skills, and integration of concepts an engineer uses in his/her day-to-day practice.

Mastery of these engineering threshold concepts, skills, and practices should indicate graduates are well on their way to becoming capable engineers. It then seems logical that the graduate attributes identified and monitored as part of an accreditation's graduate attribute assessment should be linked to these thresholds.

This research established and piloted a framework for engineering educators to examine the level to which the graduate attributes identified for engineering accreditation measure mastery of the threshold concepts identified in the integrated engineering threshold concepts inventory.

III. PROCESS

The Graduate Attribute – Threshold Concepts (GATC) framework allows an engineering program to analyze the relationship between graduate attribute key indicators and the threshold concepts identified in the IETCI. These results can be used to make curriculum and accreditation tracking decisions during the required continual improvement process.

A. *Framework*

Analysis of program data using the GATC framework is a three stage process: (1) extraction of accreditation data, (2) mapping graduate attribute indicators and exemplars to threshold concepts, and (3) interpreting the results.

The first stage requires access to the program's most recent CEAB accreditation documentation. Fig. 1 shows the result of this stage where accreditation table 3.1.2, found in the EN_6C_vXX spreadsheet, is copied exactly as is into the CEAB312 worksheet of the GATC working document.

This data is used to populate the TC Analysis mapping worksheet used in phase 2. Fig. 2 shows this transfer of CEAB data into a form where each learning activity is separated out into its own mapping row. The person or team doing the analysis now needs to identify the exemplar (problem, assignment, exam question, lab, or project) associated with the learning activity listed in the Activity column. Fig. 2 also shows two exemplars, one for each of the first two activities.

	A	B	C	D	E
1	Instructions:	List the indicators associated with each attribute together with the learning activities where the indicator has been used to assess performance of students (as highlighted in Table 3.1.1). Rows are provided but there is no expectation that they will all be used for any particular attribute. If more rows are needed, add rows as required. *Please delete the sample entries and highlighting to use this table.*			
2	Table 3.1.2:	Indicators and Learning Activities Assessed			
3	Graduate Attribute	Indicator	Relative Level		
4			Introductory	Intermediate	Advanced
5	Knowledge base	1.2 Use mathematics to describe and solve engineering problems.		MATH375	
6		1.3 Use technical knowledge to inform engineering activities.	ENGG201		
7		1.3 Use technical knowledge to inform engineering activities.			ENME339
8		1.2 Use mathematics to describe and solve engineering problems. 1.3 Use technical knowledge to inform engineering activities.			SE survey
9					
10	Problem analysis	2.1 Apply engineering knowledge and skills to solve real world problems.		ENGG349	
11		2.1 Apply engineering knowledge and skills to solve real world problems.	ENME461		
12		2.1 Apply engineering knowledge and skills to solve real world problems.			ENME585
		2.1 Apply engineering knowledge and skills to solve real world problems. 2.2 Make assumptions that successfully simplify a complex problem.			SE survey

Figure 1: GATC phase 1 – CEAB data

Graduate Attribute	Indicator	Level	Activity	Exemplar
Knowledge base	1.2 Use mathematics to describe and solve engineering problems.	Introductory		
		Intermediate	MATH375	Solve first order differential equations with applications
		Advanced		
	1.3 Use technical knowledge to inform engineering activities.	Introductory	ENGG201	Perform hydrostatic pressure calculations and basic fluid flow calculations
		Intermediate		

Figure 2: GATC phase 2 – TC analysis – exemplars

Mapping begins once an exemplar has been identified for each of the activities. Each of the threshold concepts included in the inventory is listed in a column across the top of the worksheet. Fig. 3 shows a few of the threshold concepts in the 'learning to become an engineer' and the 'thinking and understanding like an engineer' categories of the IETCI. The task for the analysis team is to determine if each exemplar maps to one or more threshold concept. It is expected that some exemplars will map, while others will not. If a map is found, the intersecting cell is marked with an 'x'. Resources including a concept map of IETCI, a summary table of the threshold concepts identified in the IETCI, and a suggested categorization and mapping of threshold concepts identified in other research studies, are provided in the spreadsheet to help analysts identify potential threshold concepts. Fig. 3 shows the first exemplar mapped to three of the threshold concepts in the abstraction, modelling, and theories section, and the second exemplar mapped to one. Once each exemplar has been examined, the mapping process is complete.

The GATC report is broken into two parts: an examination of the graduate attributes and threshold concepts, and the tracking of threshold concepts. The examination of graduate attributes and threshold concepts reports three things useful in determining if the exemplars they are tracking are ones that show the transformation learners make as they move from novice to practitioner: (1) the percentage of exemplars that are mapped to at least one threshold concept, (2) the number of threshold concepts mapped to each graduate attribute (see Fig. 4), and (3) a breakdown of which threshold concept categories (learn, think, shape) are mapped to each graduate attribute (see Fig. 5).

				Abstraction, modelling and theories							
Activity	Exemplar	use of memory	Engineering as gendered	Confidence in the mathematical models	System identification and definition	Judging whether a model is satisfactory	Proofs	Creating visual or symbolic representations	Relating visual or symbolic representations of systems to physical systems	Relating mathematical representations of systems to physical systems	Describing systems mathematically
MATH375	Solve first order differential equations with applications			X						X	X
ENGG201	Perform hydrostatic pressure calculations and basic fluid flow calculations									x	

Figure 3: GATC phase 3 – TC analysis – mapping

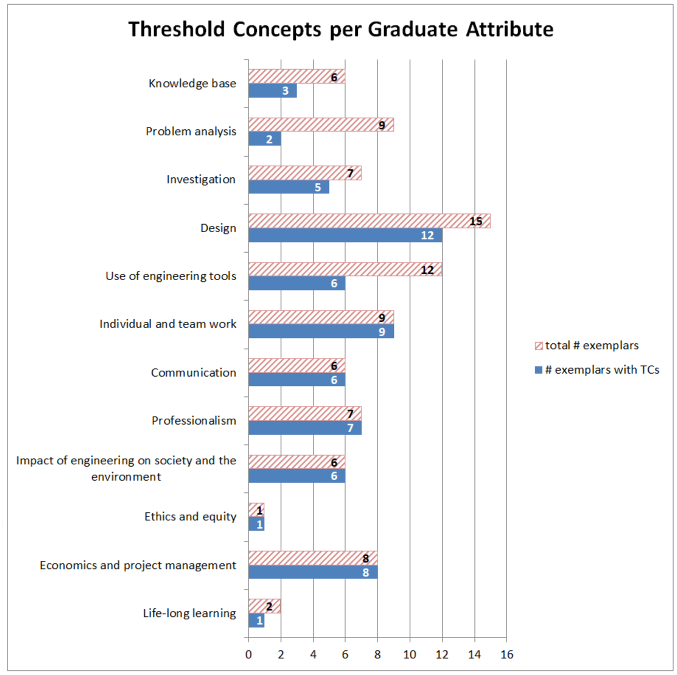

Figure 4: GATC report part 1 – grad attributes & threshold concepts

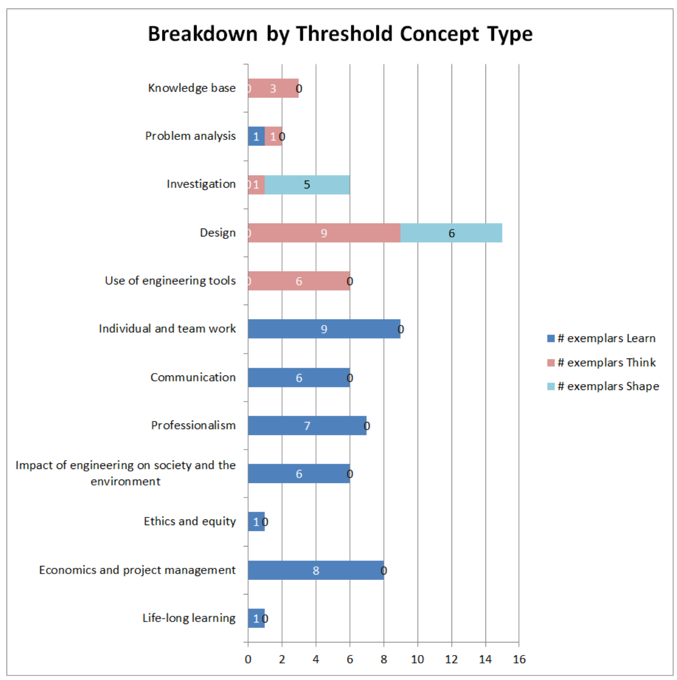

Figure 5: GATC report part 1 – breakdown by threshold concept type

The second part of the report specifies the percentage of threshold concepts that were mapped to at least one graduate attribute (see Fig. 6). It also identifies the number of mappings for each threshold concept. This allows the analysts to quickly identify any unmapped threshold concepts that are important to their discipline, and should be considered as potential exemplars.

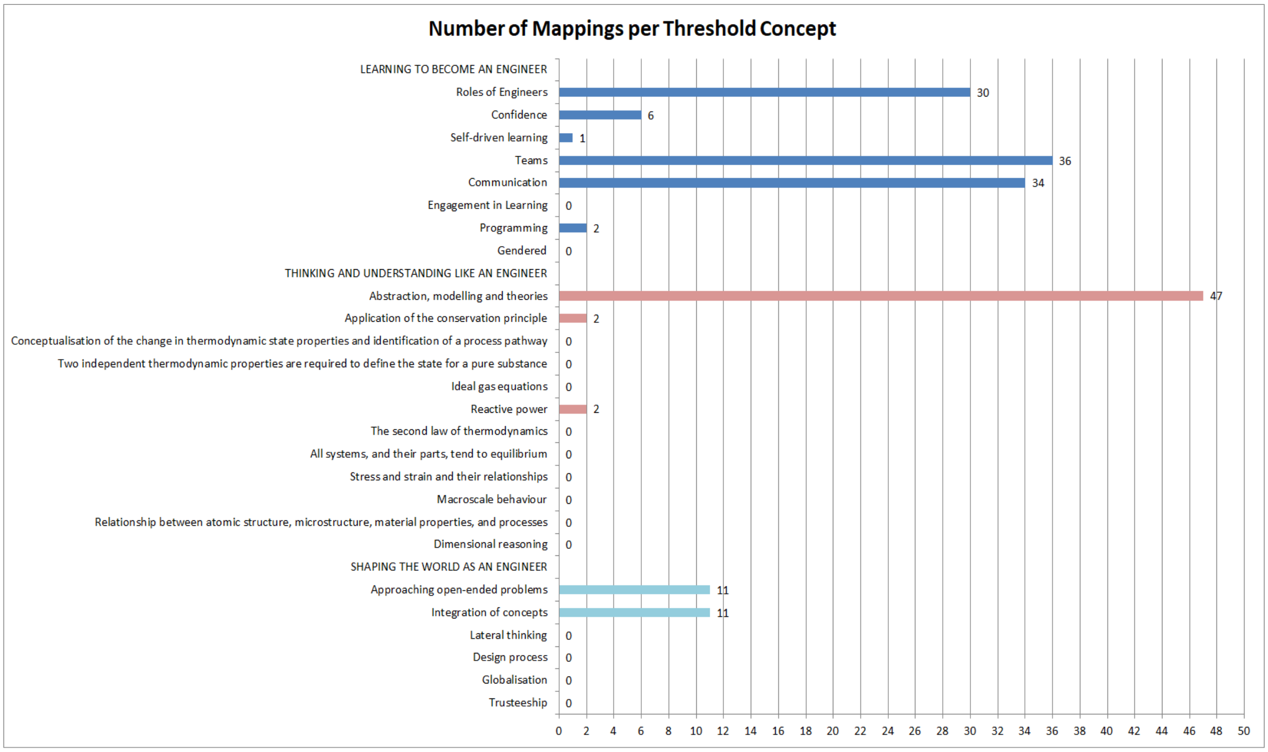

Figure 6: GATC report part 2 – number of mappings per threshold concept

B. Application

The GATC framework was piloted with two programs that underwent their CEAB accreditation reviews in 2017. It was reported to be easy to use, and in both cases took less than one hour to load the graduate attribute data, and enter and map the exemplars.

The first program had 47 exemplars with 46 mapped to threshold concepts (97.7%), while the second had 88 exemplars with 66 mapped to threshold concepts (75.0%). This percentage is not a reflection of the quality of the program or the choice of indicators. It is simply an indication of how many of the selected benchmarks are threshold concepts, and where they are focused. If a graduate attribute does not map to any of the threshold concepts, or there is an imbalance of mapping across the threshold concept types (‘learn’, ‘think’, ‘shape’), then the program should consider modifying their choice of exemplar to one that tracks a significant point in a student’s transformation from novice to practitioner.

The first program had 29 of the 57 threshold concepts mapped from its graduate attributes (59.9%), and the second program had 32 of the 57 threshold concepts mapped from its graduate attributes (56.1%). A higher percentage of mappings does not necessarily mean a "better" program. It simply identifies a threshold concept that has been associated with a number of graduate attribute exemplars. Programs are encouraged to look at the threshold concepts that have few or no mappings. If these are important concepts within the discipline, then consideration should be made to add graduate attribute exemplars to monitor student learning associated with these threshold concepts.

IV. Discussion

Users in both pilot tests recognized the value of the GATC framework as part of the continual improvement requirement of the accreditation process. It was easy to use, and helped identify areas where graduate attributes could be better mapped to discipline-specific threshold concepts. One program recognized that a critical graduate attribute indicator had inadvertently been omitted from their CEAB submission. Had the GATC framework analysis been done prior to submission this omission would have been caught. The other program identified gaps within the ‘learn’, ‘think’, and ‘shape’ categories of threshold concepts tracked and will reevaluate the choice of exemplars to provide broader coverage of these categories.

V. Future Work

Future work on the GATC framework will focus on two key areas: (1) expanding the pilot study to gather feedback from other interested programs, and (2) integrating the findings of discipline and topic specific threshold concept research into the GATC framework’s topic search resource to help users more easily map their graduate attribute indicators.

References

[1] “Canadian Engineers for Tomorrow,” Ottawa, ON, 2016.

[2] J. E. Froyd, P. C. Wankat, and K. A. Smith, “Five major shifts in 100 years of engineering education,” *Proc. IEEE*, vol. 100, no. SPL CONTENT, pp. 1344–1360, 2012.

[3] A. Cheville, “Defining Engineering Education,” *ASEE Annu. Conf.*, 2014.

[4] E. F. Crawley, J. Malmqvist, S. Östlund, and D. R. Brodeur, *Rethinking Engineering Education*, 2nd ed. Switzerland: Springer International Publishing, 2014.

[5] Staff, "About Accreditation," *Engineers Canada Website*, 2018. .

[6] "Canadian Engineering Accreditation Board: 2017 Accreditation Criteria and Procedures," Ottawa, ON, 2017.

[7] J. H. F. Meyer and R. Land, "Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines," Edinburgh, 2003.

[8] E. A. Marek, "They Misunderstand, But They'll Pass," *Sci. Teach.*, vol. 53, no. 9, pp. 32–35, 1986.

[9] D. Perkins, "The Many Faces of Constructivism," *Educ. Leadersh.*, vol. 57, no. 3, pp. 6–11, 1999.

[10] A. Rugarcia, R. M. Felder, D. R. Woods, and J. E. Stice, "The Future of Engineering Education I. A Vision for a New Century," *Chem. Eng. Educ.*, vol. 34, no. 1, pp. 16–25, 2000.

[11] J. Rhem, "Threshold concepts and troublesome knowledge," *Tomorrow's Profr.*, vol. 22, no. 4, p. 2, 2013.

[12] L. Thomas, J. E. Moström, K. Sanders, R. I. College, C. Zander, and W. Bothell, "In the liminal space : software design as a threshold skill," *Pract. Evid. Scholarsh. Teach. Learn. High. Educ.*, vol. 12, no. 2008, pp. 333–351, 2015.

[13] S. Male, "Integrated engineering foundation concept inventory," Sydney, 2012.