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Moving Towards a Research Informed Conceptual Model of Engineering Global Preparedness

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Abstract

Engineering educators are challenged to produce globally prepared graduates. Yet, sparse research has defined specific traits, characteristics, experiences, or competencies that contribute to this outcome. In this paper, we describe and present results of a research summit that was convened with a group of subject matter experts in engineering and international education to reach consensus on the skills, strategies and characteristics of globally prepared engineering students. This summit was a culminating research process that synthesized results of three rounds of a Delphi study that focused on identifying the traits, experiences, and competencies that defined globally prepared engineering graduates. The summit resulted in the semantic mapping of critical aspects of global preparedness of undergraduate engineering students. The resulting semantic map documents the relationships among engineering global preparedness and three other broad categories, some of which are particular to engineering education and others that may be applied to other higher education contexts concerned with global preparedness. In addition to global preparedness, the remaining three categories are international contextual knowledge, personal and professional qualities, and cross-cultural communication skills and strategies. The results of this research are intended to inform both engineering and international education.

Introduction

Rapidly advancing technologies, global economic integration, and hyper-connected communities have profoundly affected the landscape of the engineering profession and as a consequence, education.[1] Technical skills are no longer sufficient to be prepared as a professional engineer. Twenty-first-century engineers must also now possess well-honed communication skills and the disposition to fully engage and participate in global workforces. The necessity for engineers to work across cultures and disciplines has been increasingly spotlighted by engineering professional and educational communities as reflected in recent national reports, conferences, and publications.[2] The American Society of Mechanical Engineers brought to light a contemporary reality:

> "The economics of nations are becoming increasingly interconnected. Information technology and knowledge cross borders through international telecommunications and online services. Computer-based engineering work is handed off around the world. Business, R&D, design, manufacturing, marketing and distribution are going global and engineering and engineering standards must go with them." [3]

Impacted by global economics and advancing technologies, " … business, R&D, design, manufacturing, marketing and distribution are going global and engineering and engineering standards must go with them."[1] American engineering colleges must prepare twenty-first century engineers with not only "intellectual development and superb technical capabilities," but ability and skills for teamwork, communication, "understand economic, social, environmental, and international context of their professional activities."[2,3] Numerous prominent professional and academic organizations such as the National Academy of Engineering (and its widely quoted *The*

Engineer of 2020), the National Science Foundation, and the National Research Council have also charged engineering schools to task on preparing engineers for global workforces.[4,5,6]

This appeal has significant consequences for the engineering educator. Today many engineering programs have realized that they are responsible for producing globally prepared graduates who, by working cross culturally and across national boundaries, can effectively identify opportunities, understand global market forces, and successfully commercialize new technologies.[7] Moreover, the Accreditation Board for Engineering and Technology's (ABET) General Criterion 3, student outcome (h), requires engineering programs to demonstrate their graduates have "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." [8] The fact that ABET includes global perspective in its requirements, underscores the necessity to broaden engineering education so that future engineers are fully prepared to operate in the global working environment.

In spite of growing awareness of the importance of developing global skills in future engineers, there are growing concerns that the U.S. engineers are not yet prepared for professional practice in the global workplace. One concern is that the overall efforts of engineering schools to incorporate international experiences that promote global preparedness in the undergraduate curriculum are still "in their infancy." [2] Engineering students participate in international engineering programs in disturbingly low numbers. For example, among the 283,332 U.S. students in higher education who studied abroad for academic credit in the 2011-2012 academic year, engineering students represented only 3.9%, (11,000).[9] Moreover, the number of U.S. engineering students studying abroad has fluctuated over the past decade. There was a 1.3% increase in the number from 2010-2011 to 2011-2012; while a 9.1% decrease from 2009-2010 to 2010-2011.[7]

While there is broad agreement within the engineering community for the need to better prepare graduates for global practice, there is no consensus as to the definition of engineering global preparedness. Further, there is a paucity of research that explores pedagogical practices and formal and informal experiences that *might* contribute to engineering global preparedness. This research is essential to meet the charges of engineering organizations and to address the changing needs of engineers as they prepare for workplaces that cut across national, cultural and continental boundaries. To enhance undergraduate engineering students' global preparedness, engineering programs must first identify what constitutes a globally prepared engineer and must also identify the various ways that global preparedness can be attained both in and out of formal academia. The research presented in this paper contributes to these critical efforts and is guided by two important research questions:

1. What are the essential characteristics, skills and strategies associated with engineering global preparedness?
2. What learning experiences contribute to preparing undergraduate students for engineering global workforces?

This research team led a six-month Delphi process with 18 subject matter experts (SMEs), including a summit to discuss the research findings. As a culminating exercise, participating

SMEs created a semantic map of the attributes of a globally prepared engineer. A semantic map is a visual representation of a person's understanding of how different items may relate to each other. Four separate maps were produced by SME teams at the summit, which were then synthesized into a single map and vetted with the SMEs. A final map resulted that provides a conceptual model of the attributes that in combination lead to a globally prepared engineer. This paper describes the process by which this map was created and how this conceptual model might be used by engineering educators.

Review of the literature

Attributes and characteristics that promote global preparedness: There are numerous frameworks on intercultural or global competence in general, few on engineering global competence and only one emergent frame on engineering global preparedness.[10] Deardorff developed a ground-theory-based model of intercultural competence that she defines as the ability to interact with those from different backgrounds, regardless location.[11] Her model characterizes intercultural competence as moving from individual level (attitudes) to interaction level (outcomes). Deardorff identifies several key elements to consider in the model. First, she argues that such attitudes as respect, openness, and curiosity serve as the basis of intercultural competence. Second, she highlights critical-thinking skills as an important element of intercultural competence and states that ability to assess global perspectives represents a major attribute of it because "This deep cultural knowledge entails a more holistic, contextual understanding of a culture, including the historical, political, and social contexts."[11] Finally, she recognizes intercultural competence development as an ongoing process. Thus, it is important to assess its development over time.

Parkinson has addressed engineering global competency and suggested the attributes of a globally competent engineer. [12] From Parkinson's work, these attributes include: ability to appreciate other cultures and to communicate across cultures; familiarity with the history, government and economic systems of several target countries; ability to speak a second language at a conversational level and at a professional (i.e. technical) level; proficiency working in or directing a team of ethnic and cultural diversity; ability to effectively deal with ethical issues arising from cultural or national differences; understanding cultural differences relating to product design, manufacture and use; understanding of the connectedness of the world and the workings of the global economy; understanding implications of cultural differences on how engineering tasks might be approached; having some exposure to international aspects of topics; having had a chance to practice engineering in a global context; and viewing themselves as "citizens of the world," as well as citizens of a particular country.

Though Parkinson and Deardorff identify the necessary knowledge, skills, and attributes, in our research we expand upon these critical aspects further to define global preparedness - the readiness to engage and effectively operate under uncertainty in different cultural contexts to address engineering problems. Global preparedness brings together the set of congruent behaviors, attitudes, characteristics, and policies in a system, agency, or among professionals, enabling that system, agency, or those professionals to work effectively in cross-cultural situations.

Learning and pedagogical experiences that promote global preparedness: Universities endeavor to infuse international experiences into engineering curricula through a variety of methods including curricula and co-curricula activities. Grandin and Hirleman, for example, categorize eight types of international engineering programs that have been utilized by various Schools of Engineering across the U.S.[13] These include:

1. Double Major or Dual Degree Programs, in which students are required to obtain proficiency in a second language, complete culture courses, and study or work abroad in addition to their regular engineering courses (e.g. Pennsylvania State University, Iowa State University, and University of Rhode Island).
2. Minors or Certificates Programs lasting less than a month that address a specialized topic related to engineering in a global context (e.g. Georgia Tech, Iowa State University, Purdue University, University of Illinois, University of Michigan, University of Pittsburg).
3. International Internships, International Co-Op (e.g. Georgia Tech, MIT, University of Rhode Island, University of Cincinnati, Worcester Polytechnic University).
4. International Projects (e.g. Worcester Polytechnic Institute).
5. Study Abroad and Academic Exchange (e.g. University of Minnesota, Rensselaer, Global E3).
6. Collaborative Research Projects and Global Teaming with partners abroad (Purdue University, Harvey Mudd).
7. Service Learning Projects Abroad (University of South Florida, Worcester Polytechnic University, University of Dayton, Duke University).
8. Graduate-Level International Programs, including research experiences abroad, research collaborations with colleagues abroad, dual and joint degree programs with partner universities abroad (e.g. University of Rhode Island Dual Degree Masters and Doctoral Programs, NSF PIRE and IREE projects).

In addition, the programmatic components of such programs may significantly vary. Seeking to classify the relative nature of one program versus another, Grandin and Maher define the following parameters: (a) short-term versus long term; (b) English language or non-English language; (c) degree of cultural exposure/immersion; (d) degree of curricular integration; (e) degree of cultural/linguistic preparation for experiences abroad; (f) degree of engineering specificity; (g) degree of institutional/administrative commitment.[13]

Despite the diversity in types of pedagogical strategies, the research on the impact of these approaches for students' preparedness for global workforces has been limited.[7] In contrast, however, researchers have identified many challenges associated with the implementation of international experiences in engineering programs: limited capacity of an already content-full and highly sequenced curriculum, high costs to implement globally focused programs, and the risk of delaying graduation when international experiences are included as a degree requirement.[7, 14] These challenges indicate that a more comprehensive and integrated approach to enhance development of global preparedness in engineering students is necessary to meet the changing needs of society world-wide.

Methodological approach

Research context and participation: Data for this research was collected during a summit that convened twelve subject matter experts in engineering and international education who participated in a six-month Delphi study. The SMEs represented diverse expertise representing: 1) engineering education; 2) industry; 3) international education practitioners, specifically for engineers; 4); student assessment and evaluation; 5) international education societies. Table 1 represents the distribution of the participants in the described research Summit.

The summit followed three rounds of data collection using a Delphi Method to understand engineering global preparedness and to gain consensus on attributes of a globally prepared engineer, which were summarized from the previous Delphi rounds. The SMEs, who participated in the Delphi study, were invited to participate in the Summit (a one-day face-to-face meeting) in order to assist in developing a conceptual model of global preparedness and to provide input on ways to support global preparedness using curriculum, pedagogy, and institutional structures and resources. Although only 12 of the 18 chose to participate in the summit, the initial data to develop the maps was generated from all 18 SME during the first three rounds of the Delphi study. The majority of the industry representatives could not attend the summit due to work related commitments.

Table 1. Distribution of subject matter experts throughout the Delphi method process and at the summit

Field Representation	**Delphi Participants**	**Summit Participants**
Engineering Education	6	5
Industry Representatives	6	1
Practitioners	4	3
Assessment/Evaluation	2	2
International Education Societies	2	1
Total	18	12

Study design: During the summit, the SMEs reviewed the Delphi study results and provided feedback confirming or disconfirming its findings. The Summit included various structured activities such as a discussion on the construct groupings generated from the Delphi questionnaire results to gain consensus regarding clustering of global preparedness outcomes. Summit participants also engaged in discussions about measures of quality of international experiences and unique outcomes of global preparedness in the context of engineering.

As a culminating summit activity, the participating SMEs were divided into four sub-groups (each group consisted of 3 SMEs from different professional backgrounds) for the semantic mapping exercise. The groups were asked to create semantic maps reflecting major constructs of engineering global preparedness using data collected from the Delphi processes and to indicate relationships among constructs or categories. A strategic grouping method was employed to ensure each group covered as many professional fields as possible. Thirty-one stickers were provided to each group. Each sticker was labeled with a representation of knowledge, a skill, awareness, or a value characterizing a globally prepared engineer that had been uncovered during the Delphi process. Each group had thirty minutes to create a semantic map by grouping the item stickers and by determining the relationships among the groups. Four student recorders collected observational field notes of discussions that occurred during the summit including the semantic map exercise. The specific instructions provided to the SMEs are in the Appendix A. The initial instructions indicated the central concept to be “globally competent engineer”; however, during the summit, the SMEs and research team agreed that the central concept should be modified to "globally prepared engineer."

Analytical approach and process: Qualitative data, which were collected in the forms of summit discussion notes and semantic maps, were coded and thematically categorized using a comparative methodology. Particular attention was paid to participants' opinions about the relationships within global preparedness constructs and pedagogical global engineering experiences. Items in the semantic maps created by the four SME groups were compared using the degree of consensus, which was defined as the number of SME groups that categorized an item in the same grouping. A synthesized semantic map was generated by the research team from the four semantic maps based on the similarities and differences of the items whose degrees of consent were two or larger. This synthesized map was provided post-summit to all SME participants for feedback, including those unable to attend the summit. This feedback was incorporated into a final conceptual model. The culminating semantic map resulting from this analysis formed a conceptual model of global engineering preparedness, which compares favorably to that reported in the literature.

Results

Engineering global preparedness constructs and categorization: At the commencement of the summit, the SMEs were asked to discuss the nine grouping and categories of global preparedness that they had generated during the three round Delphi process that was a precursor to the face-to-face meeting: a) Engineering practice for the world market; b) Knowledge of the world; c) Knowledge and applications of engineering; d) Knowledge and application of business in a global context; e) Ability to solve engineering problems in a global context; f) Understanding the problem/situation in a global context; g) Ability to adapt; h) Ability to work with others; and i) Ability to communicate in a global context. The participating SMEs reached consensus on following state of these groupings. Most SMEs suggested condensing the number of groupings (or categories) from nine to a smaller number (between four and six), because they reported that there were "too many categories trying to capture the same things." For example, one SME stated, "knowledge of the world can be subsumed under understanding the problem/situation in a global context." Additionally, the SMEs chose to regroup some of the Delphi items. For example, the SMEs believed that item "self-cultural awareness" should be in the category "ability to communicate in a global context." Some SMEs also indicated that "It would be helpful to separate out knowledge and skills required to be a globally competent engineer" because "knowledge is static but skills are active."

The SMEs identified a new category in addition to those in the earlier rounds of the Delphi process as an essential component of engineering global preparedness that they termed "personal qualities." Specifically, they suggested, "Personal qualities are something we want individuals to have. We can cultivate the qualities." Additionally and particular to this category, a number of items put forth during the Delphi process were recommended by the SMEs as candidate items of personal qualities including "mental agility/flexibility," "curiosity," "self-efficacy/can-do-attitude," "desire to experience other cultures," "open positive attitude," "integrated thinking," "cultural self-awareness," "integrity," and "ability to work well with others."

Finally, the SMEs identified three new items for conceptualizing global preparedness: “life-long learning,” “creativity,” and “engineering ethics.” Some comments resonated among the SMEs in relation to these new items, such as “I feel more strongly about adding in a statement about life-long technical learning” and “Creativity is the key for me. Ethical component is also essential.” Some of the SMEs posited that “life-long learning” connected to a student’s “ability to adapt” while others felt that “creativity and critical thinking” reflected the “ability to solve engineering problems in a global context.” However, consensus was not achieved in grouping these three items during the SME discussions.

Initial group sematic mapping: As described methodologically, the SMEs with different professional backgrounds were strategically grouped to create semantic maps from the categories they had generated before the Delphi process. Table 2 (below) illustrates how the four SME groups categorized the 31 items and three newly identified items into four to six corresponding groups for their semantic maps. Note that the background of each of the three participants in the group is given first in the table, followed by up to six grouping that they developed.

Table 2. Semantic maps comparison by participant grouping

	SME Group #1 Semantic Map #1	SME Group #2 Semantic Map #2	SME Group #3 Semantic Map #3	SME Group #4 Semantic Map #4
Grouping 1	Globally engineering competencies	Globally competent engineer	Globally aware, locally competent engineer	Engineering competency
Grouping 2	Personal qualities	Personal traits	Engineering knowledge	Adaptability
Grouping 3	Context knowledge	Contextual understanding	Global knowledge	Contextual understanding
Grouping 4	Communication skills	Skills and abilities	Engineering technical skills	Teaming & communication
Grouping 5	Abilities	-	Global skills	Problem solving
Grouping 6	Foundational	-	-	-

The SME groups also indicated the relationships among groupings in the semantic maps. For example, the SME group #4 indicated a “globally prepared engineer” should have particular engineering skills and characteristics including adaptability, communication and team working ability, problem solving ability, and contextual understanding. Moreover, they believed that these components interacted with each other. Specifically, problem-solving ability was influenced by engineering competencies, adaptability, communication and teamwork, and contextual understanding, and it in turn impacted engineering competencies; contextual understanding had effects both on adaptability and problem-solving ability, while adaptability and communication and teamwork had reciprocal effect on one another.

Map syntheses: After the summit, in an attempt to synthesize the four SME group semantic maps into one map, item categorizations across the four maps were compared using “degrees of consensus,” which was defined as the number of SME groups that categorized an item in the same identified category. Appendix B represents this charting. Among the 31 items used during the semantic mapping process at the summit, 54.8% (17) had degrees of consensus higher than three, and 45.2% (14) had a degree of consensus of two. It should be noted that two of the 14 items with a degree of consensus of two appeared in multi-groupings. Two SME groups considered “Ability to understand global markets, business, politics, and trade” as a component of the “International contextual knowledge” category while the remaining SME groups thought that the item belonged to “Global engineering preparedness.” Additionally, “Ability to adapt to and integrate into different cultural environments”, was categorized by two SME groups into “Personal and professional qualities” while the remaining two SME groups classified the item as “Cross-cultural communication skills and strategies.” Two items (Cultural Awareness and International Professionalism) generated during the Delphi process failed to gain consensus (degree of consensus < 2) among SME groups. Culture Awareness was merged with another item (Self-Cultural Awareness) into a new item (Cultural Self-Awareness) during the map synthesizing process; while International Professionalism was categorized as one component of International Contextual Knowledge, as illustrated in Figure 1.

Final sematic map generation and conceptual model formation: Once the four maps were synthesized into one semantic map, all 18 SMEs who were involved in the Delphi study were asked to weigh in on the combined map by email. Their comments were then considered along with existing literature in final data analyses and construction of the final conceptual model of global preparedness. Figure 1 (below) illustrates the final results of the conceptual model.

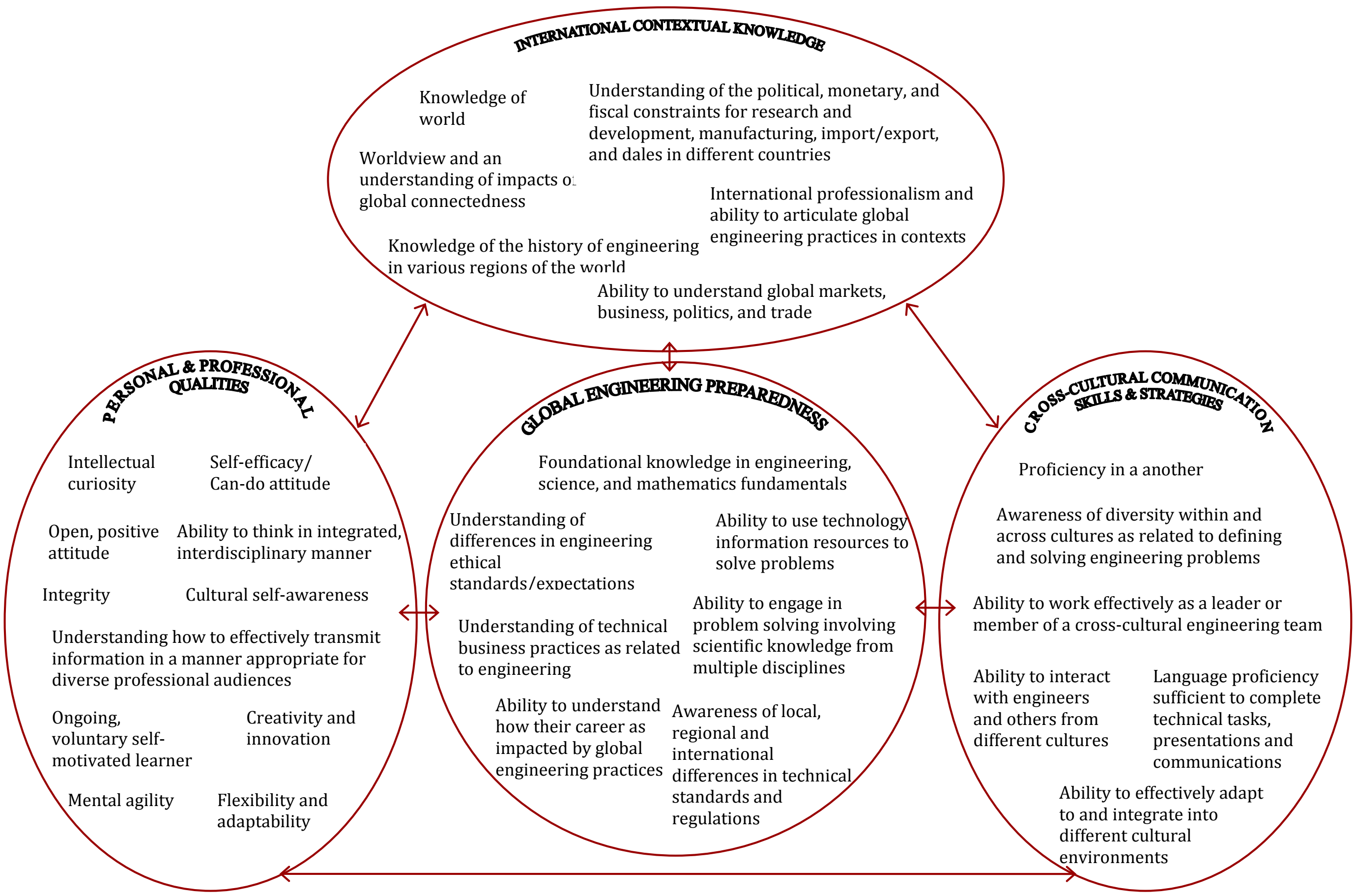

Figure 1. Conceptual model for engineering global preparedness

In final analyses of the summit results, eleven of the original items generated from the Delphi process were rephrased to reflect both feedback on the synthesis map from the summit participants and the existing literature; these then contributed to the model of engineering global preparedness. In the context of design mapping of a globally prepared engineer, the SME participants described learning experiences that scaffolding students' preparedness for global engineering workforce. They noted that proper scaffolding must be provided for effective international engineering focused experiences. They asserted, "Students need to learn how to approach problems from different perspectives." And that engineering educators must design "an engineering curriculum" which allows faculty to "use own culture as lens" to equip students with "basic skills and skills to think." This includes pre-departure type activities, as well as support and reflective journaling while abroad.

Key findings and implications

The goal for this research has been to uncover what contributes to the global preparation of engineering graduates, and our findings indicate that this extends beyond technical competency to include cross-cultural communication abilities, international contextual knowledge and personal and professional qualities. As such, international experiences that focus on engineering as well as those that focus on the more general global context both contribute to student engineering global preparedness.

The conceptual model resulting from this research can be employed as a model for developing formal and informal pedagogical practices and experiences (i.e., curricular and extra-curricular) for priming engineering students to be global prepared. Findings from the Summit discussion on international learning experiences imply that to provide a student with a high quality, meaningful international engineering experience, the following is suggested:

First, by interacting with a new environment, students can increase their understanding of different cultures and practice communication in cross-cultural settings. Students can also improve problem solving abilities in a non-US setting by being exposed to issues and challenges in new and diverse environments. Second, integrating the international experience into a well-designed engineering curriculum should be viewed as critical to student learning and not as a distraction. This will require that such experiences be designed with clear goals and objectives, appropriate timelines, and adequate resources. These findings will be considered while implementing and testing the conceptual model at multiple postsecondary educational institutions in the future study.

Conclusions

In this study, subject matter experts participated in a face-to-face summit to discuss dimensions of the global engineering preparedness and engage in semantic mapping of these dimensions. The goal was to reach consensus about the constructs of engineering global preparedness and the essential components of learning experiences to obtain it. Ultimately, this study resulted in a conceptual model of engineering global preparedness resulting from an iterative process of semantic mapping. The resulting conceptual model sets the stage for future research in engineering global preparedness. The subject matter experts and research team has recognized that preparedness differs from mere competence as it involves full preparation for engineering industries, an area that requires comprehensive research. Engineering educators can utilize the conceptual model and findings as references for designing pedagogical practices and engineering curriculum.

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Appendix A

Semantic Map
Global Competency in Engineering Outcomes

A semantic map is a visual representation of your understanding of how different items may relate to each other. You and your team are going to create a semantic map to relate the various outcomes and groupings that comprise a globally competent engineer.

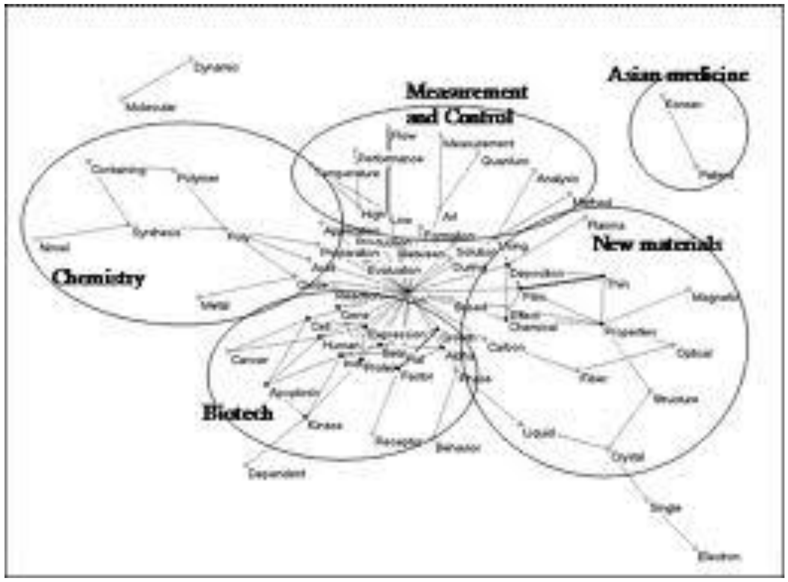
You have an envelope containing the various outcomes resulting from the Delphi Study. These are coded according to the group that was formed as a result of Rounds 2 and 3 (e.g., B.3. belongs to group B and is item 3 of the group).

Key parts to a semantic map:

- Outcomes and their groupings
- Linking lines with arrows
- Linking phrases

With your team:

1. Start your concept map in the center of your paper with the label **GLOBALLY COMPETENT ENGINEER** in the middle.
2. Arranged the outcomes/groupings on the paper with the center being the most focal point of the semantic map.
3. Once you have arranged the outcomes/groupings, create links between the various outcomes/groupings as you see necessary. You will be linking outcomes/groupings with a line which has an arrow.
4. Above the link, try to write a phrase that describes the relationship between the two entities. For example, if you were given the words ‘trees’ and ‘birds’, you might write a linking statement ‘Birds build nests in trees” with the arrow pointing to trees or a statement “trees are homes to birds” with the arrow pointing towards birds.
5. Once you are satisfied with your map, peel off the paper off the labels and stick them in place.


Measurement
and Control
Asian medicine
Chemistry
New materials
Biotech

Appendix B

Distribution of Item Degree of Consensus

Synthesized grouping	Degree of consensus	Items selected by-SME groups
Personal & Professional Qualities	≥ 3	1. Mental Agility/Flexibility 2. Curiosity 3. Self-efficacy/ Can-Do-Attitude 4. Self cultural awareness 5. Integrated thinking 6. Desire to experience other cultures; open, positive attitude 7. Integrity - put under Basic Skills
	= 2	1. Ability to adapt to and integrate into different cultural environments 2. Ability to work well with others 3. Creativity 4. Ethics 5. Life learning
	< 2	1. Cultural awareness (awareness of how national differences are important in defining and solving technical problems) 2. International professionalism (ability to articulate global engineering practices in general and how their career as a future engineer impacts engineering practices globally) 3. World view 4. Critical thinking 5. Resourcefulness
International Contextual Knowledge	≥ 3	1. Understanding of the political, monetary, and fiscal constraints in different regions and countries for R&D, manufacturing, import/export, sales, etc. 2. Knowledge of world geography 3. Knowledge of social/cultural/political/context for engineering problems
	= 2	1. Knowledge of the history of engineering in various regions of the world 2. Ability to understand global markets, business, politics, and trade 3. World view (understanding impacts of global connectedness)
	< 2	1. Cultural awareness (awareness of how national differences are important in defining and solving technical problems) 2. International professionalism (ability to articulate global engineering practices in general and how their career as a future engineer impacts engineering practices globally) 3. Historical understanding
Global Engineering Preparedness	≥ 3	1. Awareness of local/regional differences in technical standards and regulations 2. Engineering ethics, including awareness for differences in ethical standards/expectations across countries and cultures 3. Foundational knowledge in engineering, science, and mathematics fundamentals
	= 2	1. Global engineering practices 2. Ability to use technology information resources to solve problems 3. Technical business practices infused with engineering (i.e., supply chain type issues) 4. Ability to understand global markets, business, politics, and trade 5. Problem solving involving scientific knowledge from multiple disciplines being applied to non-US centered problems (not just problem solving; it's why we need the engineers; understanding of cross cultural similarities and differences in practice; ability to adapt to a project to local circumstances) 6. Ability to interact with engineers from different cultures

	< 2	1. Cultural awareness (awareness of how national differences are important in defining and solving technical problems) 2. International professionalism (ability to articulate global engineering practices in general and how their career as a future engineer impacts engineering practices globally)
Cross-cultural Communication Skills & Strategies	≥ 3	1. Cross cultural communication (intercultural communication skills; strategies; comparative analysis) 2. Proficiency in another language 3. Global communication in using the language in context within the country 4. Technical proficiency in a foreign language
	= 2	1. Basic communication skills (basic language; communicative) Ability to interact with engineers from different cultures 2. Ability to adapt to and integrate into different cultural environments 3. Ability to work effectively as a leader or member of a cross-cultural technical team
	< 2	N/A