Using Q-Sort to Prioritize Concepts for Inclusion in an Engineering Leadership Development Assessment Instrument: A Work in Progress

Pamela Edith Campos Valles, University of Texas at El Paso

Pamela E. Campos Valles is a master's research assistant in the Department of Engineering Education and Leadership at The University of Texas at El Paso. She is pursuing a MS of Engineering with concentrations in biomedical engineering and engineering education. Her research focuses on the development of an assessment instrument to evaluate engineering leadership development, drawing on the perspectives of engineering professionals to identify the skills and characteristics that define effective engineering leaders. Pamela served as the marketing chair for the American Society of Mechanical Engineers student chapter, participating in the regional student leader weekend.

Stephanie Jimenez, University of Texas at El Paso
Dr. Lori Houghtalen, University of Texas at El Paso

Lori Houghtalen is an Assistant Professor in the Department of Engineering Education and Leadership at The University of Texas at El Paso. Dr. Houghtalen's research interests include career transitions of students and engineering faculty and engineering leadership assessment. Her teaching experience has been focused on designing industry-based senior capstone courses and leadership and professional development for undergraduate engineering students.

Dr. Meagan R. Kendall, University of Texas at El Paso

An Associate Professor at The University of Texas at El Paso, Dr. Meagan R. Kendall is a founding member of the Department of Engineering Education and Leadership. With a background in both engineering education and design thinking, her research focuses on how Latinx students develop identities as engineers and navigate moments of identity interference, student and faculty engineering leadership development through the Contextual Engineering Leadership Development framework, and promoting student motivation. Dr. Kendall is the Past Chair of the Engineering Leadership Development Division of ASEE.

Using Q Method to Prioritize Concepts for Inclusion in an Engineering Leadership Development Assessment Instrument: A Work in Progress

Abstract

In response to accreditation requirements and calls for more holistic engineering education, programs worldwide are grappling with how to facilitate the professional development of engineering students, particularly in relation to their leadership development. These programs have necessarily sought ways to evaluate whether their pedagogical approach has a measurable impact on their students' leadership development. Though instruments for general leadership assessments have existed for some time, as noted at the ASEE 2023 annual conference, the engineering leadership research community still highlights a need for a new assessment instrument.

Our goal is to develop a survey instrument that measures students' engineering leadership development. Our first step in this process is to solicit input from a range of current and future engineering leaders to explore how they prioritize aspects of engineering leadership. In this paper, we pilot our method for collecting input from individuals familiar with engineering leadership. Based on the results of this study, a refined method will be generated for use in data collection with a broader audience.

We apply Q methodology to examine how engineering leaders and managers prioritize various aspects of engineering leadership for inclusion in the survey instrument. To generate our Q set, we leverage the Contextual Engineering Leadership Development framework to identify relevant theories from which potential survey items can be extracted. In piloting our method, nine mid-level and senior engineering leaders and managers participated in a Q sort involving 60 items.

Using exploratory factor analysis, we identified three key factors that correspond to three viewpoints of engineering leadership development. Each viewpoint emphasized a different aspect of the CELD framework; viewpoint 1 highlighted a leadership development model focused on team effectiveness and affective behavior, viewpoint 2 emphasized the importance of fostering an awareness of potential impact and a robust engineering identity; and viewpoint 3 focused on emotional intelligence and social awareness as essential components of leadership development. These factors offer preliminary insights into the dimensions of engineering development that mid-level and senior engineering leaders and managers value in this pilot study.

Q methodology has proven to be an effective tool for capturing and interpreting the complex perspectives of practicing engineering leaders and managers, enabling us to refine our approach to measuring engineering leadership development. This instrument will allow us to validate and refine the proposed CELD model by systematically measuring key aspects of students' engineering leadership development. The implications for engineering education are significant, as this framework can guide curriculum design, inform instructional strategies, and enhance the overall development of future engineering leaders.

Introduction

The past two decades have seen considerable growth in engineering leadership (EL) programs. This growth is in response to two primary driving forces: shifting accreditation requirements [1] and calls for more holistic engineering education [2]. These programs have sought ways to evaluate whether their pedagogical approaches have a measurable impact on the leadership development of engineering students. Documenting this impact serves two important roles: 1) it provides feedback to support the continued growth of individual students and programs, and 2) it provides evidence for return on investment [3]. For instance, Northeastern University employs a custom assessment instrument to evaluate graduate students' engineering leadership development throughout their program [4]. Their assessment provides results that help tailor students' individual development plans. At the University of Kentucky, evaluators distributed a survey to 10 years of program alumni to assess the influence of an engineering leadership development program [5]. Their assessment focuses on whether students demonstrate achievement of program outcomes as alumni rather than providing insight into how students' engineering leadership skills evolved while in the program. Due to their localized nature, these and other existing instruments are not sufficiently transferable. Practitioners, developers, and researchers have identified the need for an engineering-specific definition and approach to leadership development and, therefore, assessment [6], [7]. Providing a transferable framework with consistent metrics would enable diverse programs to leverage a shared assessment of the leadership skills developed across their programs. Furthermore, aligning the assessment with emerging models of EL development could support an integrated and prepared engineering workforce.

Considering the growth in undergraduate engineering leadership development programs and the vital role that feedback plays in developing engineering students' professional skills, our overarching research goal is to develop a survey instrument that:

- Assesses undergraduate students' EL development
- Is aligned with emerging definitions and models of EL development
- Is sufficiently transferrable for comparison across programs

The survey instrument development process typically begins with generating survey items based on theory and expert feedback [8]. Accordingly, our first step is to solicit input from various engineering leaders to explore how they prioritize aspects of engineering leadership. In this paper, we investigate the use of Q methodology for prioritizing potential concepts for inclusion in an engineering leadership development instrument by conducting a pilot study in which we collected input from individuals familiar with engineering leadership. A refined method will be developed based on the results of this study for use in data collection from a broader audience. We therefore seek to answer the following research question: *Is Q methodology an appropriate approach for prioritizing qualitative concepts related to Engineering Leadership?*

Instrument Development Framework

In the larger study, we are leveraging the six-step instrument development process described by [8]. The steps include item generation, questionnaire administration, initial item reduction, confirmatory factor analysis, validity checking, and replication. In the present paper, we are focused on piloting our item generation process using Q methodology.

Item generation is the process of creating items for a survey instrument that adequately measures the constructs of interest in the theoretical foundation. This is typically accomplished through a deductive (theory-driven), inductive (emergent and respondent or expert-driven), or combined approach. The generated items then undergo a series of analyses to extract a parsimonious set and evaluate the instrument's construct validity, ensuring it measures what it is intended to measure. This is demonstrated by examining content validity, criterion-related validity, and internal consistency [8].

Methods – Q sort pilot

Q methodology combines qualitative and quantitative data collection. Specifically, it enables researchers to conceptualize individual viewpoints by analyzing and interpreting data sets of qualitative information [9]. This method correlates the participants' sorts with each other and depicts the agreement and disagreement between participants' responses. Further, it identifies the patterns in the organization of the sorts to extract factors that characterize similar viewpoints. The mathematical standardization of the method facilitates quantitative analysis of personal beliefs to inform item generation [10]. The results from this pilot study will inform item refinement before a broader Q sort, ultimately shaping the final survey instrument for validation. To employ Q method, we: 1) deductively generated a set of potential items to use in Q sort (our concourse), 2) reduced it to a sample of 60 items (our Q set), 3) selected a pilot sample of participants (our P set), 4) participants conducted the item sorting into a weighted response grid (the Q sort), 5) extracted factors representing leadership viewpoints, and 6) interpreted these based on item loading and representative statements [10].

Steps 1 and 2. Develop the Concourse and Q Set

In line with the six-step process described previously, we begin by generating items. Our guiding framework is the Contextual Engineering Leadership Development (CELD) Framework [11]. The CELD Framework recognizes that to develop as engineering leaders, students must simultaneously enhance their technical expertise while learning to lead increasingly technical projects in an engineering setting. Initially, the focus is on the individual's development of effectual behaviors, such as emotional intelligence, implicit bias, identity, and motivation. As engineering projects become more complex and require interdisciplinary knowledge, development shifts toward collaboration, honing communication, teamwork, and other interpersonal skills vital for effective teamwork. As students engage in projects that have lasting effects on themselves, their teams, their communities, or society, contextual awareness becomes a critical focus, encompassing an understanding of the long-term implications of their work.

We utilized a deductive approach to generate our concourse of 72 potential items by examining theoretical frameworks related to the four CELD constructs and extracting words and phrases linked to key components of those frameworks. We derived our Q set of 60 items from the concourse by eliminating sufficiently similar concepts that appeared across multiple frameworks (see Appendix for complete Q set). Thirty to sixty items in a Q set is common [10].

Steps 3 and 4. Q Sort Data Collection

The next step involved soliciting input from a range of engineering leaders to explore how they prioritize aspects of engineering leadership. We piloted the use of Q sort with nine mid-level and senior engineering leaders and managers of engineers, our P set. This pilot leveraged a convenience sample, as all participants were members of an advisory board for an undergraduate engineering leadership program. Therefore, these participants are familiar with engineering leadership as a desired educational outcome of the department's program. Participants were informed of the nature of the study and that the statements were being considered for inclusion in a survey instrument to assess undergraduate student engineering leadership development. The study protocol received approval from the research team's Institutional Review Board.

For the in-person data collection, each participant received a set of cards containing the Q statements (one statement per card), a set of initial sort categories, and a response grid containing 60 squares for placing the Q statements (Figure 1). Participants were encouraged to sort the statements using a two-step process: first, to sort the statements into the high-level categories of "Disagree," "Neutral / Unsure," and "Agree." Then, participants sorted the statements into a forced normal distribution using the provided grid (Figure 1).

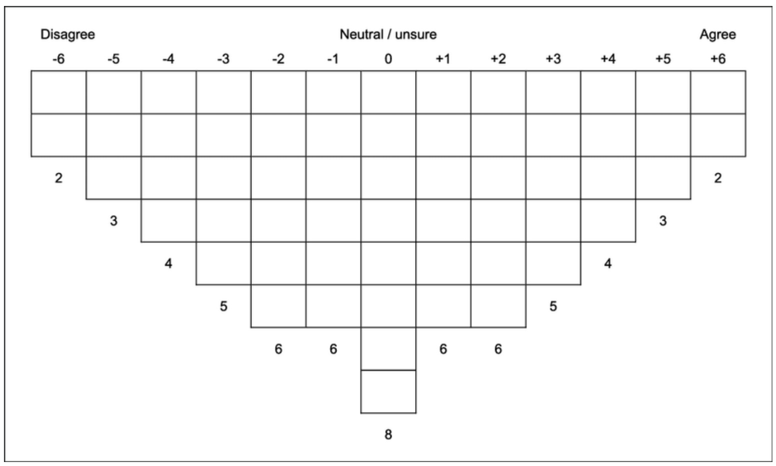

Figure 1. Q sort response grid for 60 Q statements [12]

Participants sorted 60 statements based on their perception of its importance to engineering leadership, drawing from their experiences as practicing engineers or managers of engineers. Before the sorting began, they noted any unclear statements by specifying their interpretations of those statements in writing on the back of the card. Additionally, participants received blank cards to add any statements to their sorting activity, if desired.

Participants spent 10 to 15 minutes sorting the statements onto the response grid. Most participants began by placing statements from their "Agree" sort pile onto the right side of the response grid and working to the left. When a participant completed the activity, the response grid was photographed, and their set of Q statements was collected to enable documentation of any participant notes. Each participant then completed a short demographic survey asking what industry they work in, years of experience in engineering or managing engineers, academic background, gender, and professional licenses or certifications.

Steps 5 and 6. Factor Analysis using KADE

The first step in the analysis involved transcribing participants' Q sort data into a spreadsheet for analysis using KADE, a specialized software designed for Q sort data analysis and visualization [13]. This software ensures data integrity by scanning the spreadsheet data and blocking incomplete sorts. Due to incomplete sorts, two participants were excluded. KADE performs an exploratory factor analysis, sorting participants into groups (i.e., factors) based on the similarity of their sorts. By examining the factor loadings, Z-scores, and rankings of the Q-sort statements, we can interpret the factors as distinct viewpoints of how participants prioritize the components of engineering leadership [14]. To understand the similarities between each participant's sort, the software generates a correlation matrix, which measures the linear association between two sets of scores.

Results and Discussion

Participant Demographics

All participants completed a demographic survey that included questions about their specific work industries, years of experience, degrees obtained, gender, and any licenses or certifications. This information was collected to help interpret the resulting viewpoints, as participants leveraged their backgrounds when sorting the statements. The seven participants included in the data analysis possessed a wide range of experience, spanning from 2 to 44 years. Six individuals have a bachelor's degree in engineering, five hold a master's degree in various fields, and two hold professional licenses as a Professional Engineer and Project Management Professional. Six participants identified as men, while one identified as a woman.

Factor Analysis Results

To select the appropriate factor solution, eigenvalues were calculated for each principal factor and visualized in a scree plot (see Appendix, Figure 2). Based on the inflection point in the scree plot and each factor's explained variance, we chose a three-factor solution to account for as much variability as possible [10].

We analyzed statements based on their factor array; this number represents the average loading of individual Q sort statement positions related to the selected factors, using a rating scale of -6 to +6. Statements identified as statistically significant ($p < 0.01$), are recognized as unique within the given factor. Each distinguishing set of statements reflects the overall viewpoint of the corresponding factor, indicating how much each factor values or devalues a statement compared to other factors. Twenty-nine distinguishing statements were identified across the three chosen factors (see Appendix, Table 1). In the full study, these distinguishing statements would become the initial set of items in the survey instrument.

Based on reviewing the distinguishing statements for each factor, the resulting viewpoints of engineering leadership development can be described as:

- *Team Effectiveness and Affect*: This viewpoint emphasizes team effectiveness and core engineering skills as essential for engineering leadership development, while traits like emotional intelligence and human agency are less significant.
- *Impact Awareness & Identity as an Engineer*: This viewpoint idealizes engineering practice, emphasizing identity and professional responsibility while considering emotional intelligence and leadership identification unimportant, like factor one.
- *Emotional Intelligence & Social Awareness*: Unlike the previous two factors, this viewpoint prioritizes a high understanding of emotional intelligence and social understanding when dealing in collaborative environments.

Intent to Continue Using Q Method Based on Pilot Study Results

This study aims to evaluate the use of Q methodology to collect input from current and future engineering leaders on how they prioritize aspects of engineering leadership as a component of our item generation process. This study identified three viewpoints that align with engineering leadership theories and previous studies [14], [15] that define the various orientations for understanding engineering leadership; this convergence of findings serves as one source of validation for our proposed process. Despite the limited sample size, the results show distinct and relevant differences in how the participants prioritize leadership. The method setup and factor analysis enabled the researchers to extract diverse perspectives and make decisions about prioritizing items based on statistical analysis. This pilot study confirms that Q methodology is a viable approach for investigating subjective viewpoints on engineering leadership development.

Insights and Limitations Informing Future Work

As this is a pilot study, we urge readers not to generalize the results, as they may not encompass the full spectrum of perspectives found in a larger population. As noted, this study used a convenient P sample consisting entirely of members from an engineering leadership program's advisory board. As a result, participants may have relied on perspectives aligned with the program's views on engineering leadership rather than their individual opinions.

Instead of focusing on the implications of our identified viewpoints, we note insights from piloting this Q method approach worth sharing. In future data collection, we recommend digitizing the process to enhance ease and accuracy. Software is available for running digital Q method studies (e.g., qmethodsoftware.com), giving us access to a broader participant pool by eliminating the need to collect data in person. Reading 60 statements can be time-consuming; therefore, we recommend using concise statements and randomizing their order to minimize any impacts of survey fatigue. Additionally, we recommend using a scale that anchors to the terms least/most relevant, important, or representative of engineering leadership development. Participants commented on how all statements were relevant, so using agree or disagree felt inaccurate. We also intend to provide a glossary with more detailed descriptions of the Q statements for participants to reference as needed. The research team also noted concerns during data collection and analysis about differences between how undergraduate students and professionals may interpret the statements. Therefore, a think-aloud protocol with undergraduate engineering students is recommended and will be employed to better understand interpretations of the Q statements process and, ultimately, the survey items.

Conclusion

This pilot study demonstrated the viability of the Q methodology for exploring individuals' subjective prioritization of leadership qualities. Seven Q sorts led to the identification of three factors with twenty-nine distinguishing statements. These findings provide a foundation for future research and highlight the advantages of Q methodology in the analysis of subjective concepts. The next steps in this work will complete the six-step process for instrument development and expand the sample size and diversity of participants to reveal broader insight into the prioritization of engineering leadership development.

References

[1] “Criteria for Accrediting Engineering Programs, 2024 - 2025 - ABET.” Accessed: Nov. 27, 2024. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2024-2025/#GC3

[2] E. D. Lindsay, R. G. Hadgraft, F. Boyle, and R. Ulseth, “Disrupting Engineering Education,” in *International Handbook of Engineering Education Research*, 1st ed., New York: Routledge, 2023, pp. 115–133. doi: 10.4324/9781003287483-7.

[3] B. J. Novoselich and D. B. Knight, “Measuring a moving target: Techniques for engineering leadership evaluation and assessment,” *New Directions for Student Leadership*, vol. 2022, no. 173, pp. 63–71, 2022, doi: 10.1002/yd.20480.

[4] S. Pitts, S. McGonagle, and S. W. Klosterman, “Developing Engineering Leaders using Engineering Leadership Capabilities and Leadership Labs,” presented at the 2013 ASEE Annual Conference & Exposition, Jun. 2013, p. 23.399.1-23.399.16. Accessed: Nov. 20, 2024. [Online]. Available: https://peer.asee.org/developing-engineering-leaders-using-engineering-leadership-capabilities-and-leadership-labs

[5] L. Holloway, T. W. Lester, and J. A. Colella, “Engineering Leadership Development Program – a Tenth-year Review and Assessment,” presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018. Accessed: Feb. 20, 2024. [Online]. Available: https://peer.asee.org/engineering-leadership-development-program-a-tenth-year-review-and-assessment

[6] B. Novoselich, M. Handley, and M. Kendall, “Shaping the Engineering Leadership Research Agenda: Results of a 2022 Special Session,” in *2023 ASEE Annual Conference & Exposition Proceedings*, Baltimore , Maryland: ASEE Conferences, Jun. 2023, p. 44211. doi: 10.18260/1-2--44211.

[7] M. Kendall, B. Novoselich, M. Handley, and M. Dabkowski, “Mapping Engineering Leadership Research through an AI-enabled Systematic Literature Review,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Feb. 20, 2024. [Online]. Available: https://peer.asee.org/mapping-engineering-leadership-research-through-an-ai-enabled-systematic-literature-review

[8] T. R. Hinkin, “A brief tutorial on the development of measures for use in survey questionnaires,” *Organizational research methods*, vol. 1, no. 1, pp. 104–121, 1998.

[9] K. Churruca *et al.*, “A scoping review of Q-methodology in healthcare research,” *BMC Medical Research Methodology*, vol. 21, no. 1, p. 125, Jun. 2021, doi: 10.1186/s12874-021-01309-7.

[10] S. Watts and P. Stenner, *Doing Q Methodological Research: Theory, Method and Interpretation*. SAGE Publications Ltd, 2012. doi: 10.4135/9781446251911.

[11] M. Kendall, D. Chachra, K. Roach, E. Tilley, and K. Gipson, “Convergent Approaches for Developing Engineering Leadership in Undergraduates,” in *2018 ASEE Annual Conference & Exposition Proceedings*, Salt Lake City, Utah: ASEE Conferences, Jun. 2018, p. 30225. doi: 10.18260/1-2--30225.

[12] P. Stenner *et al.*, “Self-management of chronic low back pain: Four viewpoints from patients and healthcare providers,” *Health Psychology Open*, vol. 2, no. 2, p. 2055102915615337, Jul. 2015, doi: 10.1177/2055102915615337.

[13] S. Banasick, “KADE: A desktop application for Q methodology,” *JOSS*, vol. 4, no. 36, p. 1360, Apr. 2019, doi: 10.21105/joss.01360.

[14] M. R. Kendall, D. Chachra, K. Gipson, and K. Roach, “Motivating the need for an engineering-specific approach to student leadership development,” *New Directions for Student Leadership*, vol. 2022, no. 173, pp. 13–21, 2022, doi: 10.1002/yd.20475.

[15] C. Rottmann, R. Sacks, and D. Reeve, “Engineering leadership: Grounding leadership theory in engineers’ professional identities,” *Leadership*, vol. 11, no. 3, pp. 351–373, Aug. 2015, doi: 10.1177/1742715014543581.

Appendix

60-item Q set Used in this Pilot Study

1. Adaptability
2. Perceive emotions of others
3. Recognize influence on others' emotions
4. Emotional self-regulation
5. Self-esteem
6. Stress management
7. Exercise autonomy
8. Recognize how assigned tasks are relevant to me
9. Self-efficacy (an individual's belief in their capacity to perform)
10. Self-control
11. Make intentional choices
12. Take intentional action
13. Recognition as an engineer
14. Interest in engineering
15. Competence as an engineer
16. Recognition as a leader
17. Interest in leading
18. Competence in leading
19. Self-critical
20. Draw insights from reflection
21. Give and receive feedback
22. Self-directed learning
23. Reliable
24. Relational skills
25. Mutual performance monitoring
26. Backup behavior
27. Team orientation
28. Promote shared mental model
29. Create supportive climate
30. Define roles
31. Monitor performance
32. Offer encouragement
33. Mange conflict
34. Sensemaking
35. Planning
36. Assign tasks
37. Coordinate member activities
38. Communicate effectively
39. Meet objectives
40. Curiosity about others' perspectives
41. Recognize strength in others
42. Compassion
43. Empathy
44. Identify diverse social and cultural norms
45. Recognize influence of biased systems and structures
46. Recognize influence of racist systems and structures
47. Understand historical behavioral norms
48. Understand environmental impact
49. Understand factors impacting sustainability
50. Understand economic impact
51. Recognize impact of work on various stakeholders
52. Recognize ethical responsibilities
53. Frame and solve problems
54. Design to address specified needs
55. Analysis
56. Tinkering
57. Recognize professional responsibilities
58. Experimentation
59. Apply principles of engineering
60. Sense of belonging in engineering

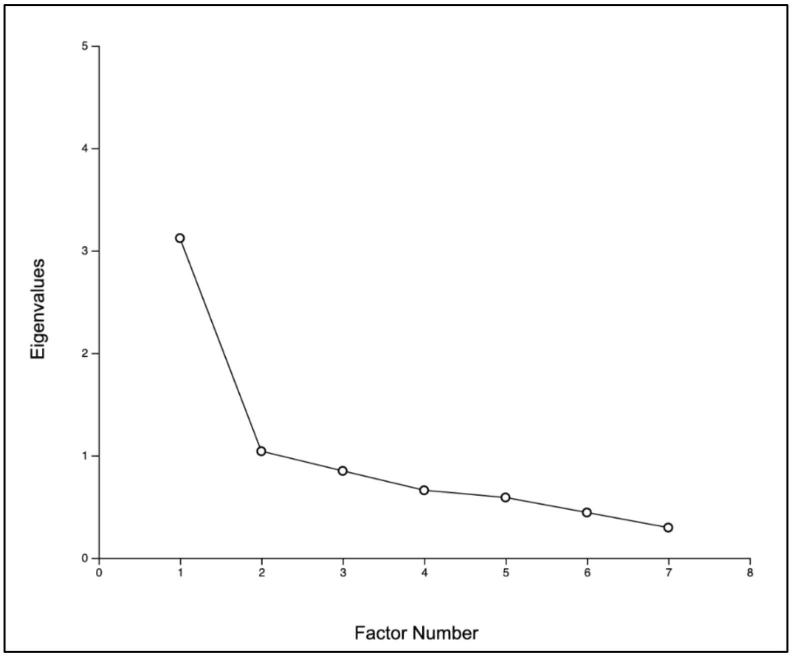

Figure 2. Eigenvalues scree plot

Table 1. The factors' distinguishing statements

	Factors/Viewpoints		
	1	2	3
Indicators	Meet objectives Apply principles of engineering Experimentation Team orientation Design to address specified needs Coordinate member activities Interest in engineering Recognize ethical responsibilities Tinkering Self-control Self-esteem Perceive emotions of others	Apply principles of engineering Competence as an engineer Recognize professional responsibilities Understand economic impact Analysis Understand environmental impact Understand factors impacting sustainability Monitor performance Self-critical Competence in leading Understand historical behavioral norms Self-esteem Exercise autonomy Perceive emotions of others Interest in leading Recognition as a leader	Self-esteem Emotional self-regulation Empathy Compassion Perceive emotions of others Apply principles of engineering Competence as an engineer