Progress on an Engineering Leadership Development Instrument: Initial Item Generation and Reduction

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Abstract

The need for a common instrument for assessing engineering leadership development has grown as accreditation standards and engineering education more broadly emphasize holistic student development and outcomes. Programs worldwide struggle to evaluate their impact on engineering students' leadership development, largely because of a lack of consensus on engineering-specific definitions of leadership and development strategies. Moreover, current instruments are often tailored to individual programs, limiting their generalizability and cross-context applicability.

To address these challenges, our work leverages the Contextual Engineering Leadership Development (CELD) framework and Q methodology to generate and reduce items. In our pilot research, we demonstrated the viability of Q methodology for exploring how engineering leaders prioritized 60 leadership statements, yielding three distinct viewpoints and 30 distinguishing statements. This process highlighted opportunities for improvement and the need for broader data collection.

In the present study, we expanded data collection via an online platform to include practicing engineers from diverse industries across North America, capturing a wide range of perspectives on engineering leadership. Our sample of practicing engineers (n = 27) varies by region, gender, race, and professional background, thereby providing a comprehensive understanding of how engineering leadership is perceived. We also conducted 10 think-aloud interviews to assess whether participants interpreted the 60 Q statements as intended, revising them as necessary. We collected data using the Q Method Software online platform, which facilitated Q sorts and the collection of survey data on participant demographics and professional experience. The data collected through Q Method Software was analyzed using KADE to perform a factor analysis of the Q sorts. The data analysis produced three composite Q sorts that capture participants' viewpoints of engineering leadership and allowed us to identify 30 distinguishing and 2 consensus statements. Distinguishing statements, shown by z-score differences, highlight unique

perspectives, while consensus statements, with similar z-scores across viewpoints, indicate shared understanding. The statements were then leveraged in our item reduction process.

Alongside data collection, we developed a preliminary set of survey items for the 60 Q statements. Since each statement corresponds to an aspect of engineering leadership backed by existing bodies of literature, items were adapted from established survey instruments. To facilitate item reduction from the preliminary set of 464 survey items, we use the Q sorts results to eliminate statements and their corresponding survey items that do not align with distinguishing and consensus statements. Doing so ensures that the final instrument evaluates the constructs that are broadly important as well as those that define distinct engineering leadership viewpoints, while using the fewest possible items. Using this approach, we have narrowed our survey to 247 items, approximately 8 per distinguishing and consensus statement. Additional refinement is needed to reduce the number of items to our target range of 4 to 6 per Q statement, which is a practical range that allows us to test for item homogeneity. Following ongoing refinement and validation, this instrument will support refinement of the CELD framework and inform curriculum design, instructional strategies, and assessment practices, contributing to the preparation of future engineering leaders.

1. Introduction

The engineering leadership field has seen incredible growth in recent years [1]. With the support of groups like the ASEE LEAD division, this momentum continues, as calls for holistic engineering education and evolving accreditation requirements persist [2], [3]. Even with all this progress, engineering leadership (EL) programs still need an assessment instrument to measure their effectiveness and alignment with industry demands [4]. Such an instrument can also provide insight into student growth and a platform for students' reflection on their leadership development [5]. This paper is part two of an ongoing project to develop a survey instrument that measures engineering leadership at the undergraduate level.

Our overarching study leverages the MEASURE approach, a 7-step process for instrument development and validation [6]. The MEASURE approach is best summarized by the following acronym: **M**ake the purpose and rationale clear; **E**stablish an empirical framework; **A**rticulate a theoretical blueprint; **S**ynthesize content and scale development; **U**se expert reviewers; **R**ecruit participants; and **E**valuate validity and reliability [6]. Here, we also use the acronym to organize our paper and indicate our current stage in the process.

1.1 Make the purpose and rationale clear

The purpose of this survey instrument is to (1) assess undergraduate student leadership development, (2) align with emerging definitions and models of EL development, and (3) create a sufficiently transferable assessment for use across programs. In the first part of this work [5], we examined the state of current engineering leadership assessments and their limitations, and the benefits of developing a transferable instrument, including shared metrics across programs, assessment of student leadership skills, and alignment with engineering professionals' experience.

1.2 Establish an empirical framework

To provide a framework for this instrument, we leverage the Contextual Engineering Leadership Development (CELD) framework. This framework conceptualizes engineering leadership as a developmental, socio-technical process through which students learn to integrate technical competence with professional and contextual capacities as the scope and impact of their work expands [7]. Originally derived from a qualitative study of multiple engineering leadership programs and a synthesis of engineering education and leadership literature, CELD provides a shared structure for organizing engineering leadership development experiences across curricular and co-curricular settings. The framework consists of four interrelated elements: *Technical mastery* reflects students' growing ability to apply engineering knowledge, skills, and practices to increasingly complex problems. *Effectual behavior* captures individual-level capacities such as self-awareness, emotional intelligence, agency, motivation, and identity, which shape how students engage with leadership opportunities and exercise influence. *Teamwork* encompasses the collaborative, communication, and coordination skills required to work effectively in engineering teams, including managing conflict, sharing leadership, and supporting collective performance. Finally, *contextual awareness* represents students' ability to recognize and account for the broader social, ethical, cultural, and societal contexts in which engineering work occurs, particularly as projects extend beyond the individual and team to affect communities and society.

Together, these four elements emphasize how engineering leadership development is not linear or role-based, but evolves as students learn to align who they are, how they work with others, what they know technically, and how their engineering decisions shape the world around them. Because this framework emerged from analyzing how different EL programs develop engineering leadership in undergraduate students, the CELD framework supports the development of an assessment instrument that is generalizable across engineering leadership programs. Furthermore, it aligns with emerging definitions of engineering leadership [8] and with other case-study analyses of EL development [9].

1.3 Articulate theoretical blueprint

In our pilot study [5], we examined the feasibility of using Q methodology to prioritize concepts for inclusion in our survey instrument and to inform item generation. We leveraged the CELD framework to generate a concourse of 60 Q statements through a deductive process of extracting words and phrases from existing theoretical frameworks associated with the key components of the four elements of CELD. Table I in the Methods section summarizes existing instruments and theories aligned with each CELD domain, along with the number of survey items extracted from each. In this study, Q methodology is being used iteratively to both validate our overall direction and strengthen item quality as the instrument develops.

1.4 Synthesize content and scale development

This paper explores our pilot approach to the "Synthesize content and scale development" stage of MEASURE, drawing on the scale development process described in [10]**.** For this, we digitized the Q method process and revised Q sort statements based on insights from our pilot administration. The emergent factors from this Q study were analyzed and interpreted based on their distinguishing statements (the findings from this will be the focus of another publication). Our next step was to generate potential survey items for the final set of Q statements. To this end, we extracted items from existing surveys that measure a variety of constructs, such as leadership self-efficacy, an engineer's impact on society, and one's ability to inspire a shared vision. We distilled the item pool by mapping each candidate item to one or more of the 60 Q-sort statements. Then, items associated with any distinguishing and full consensus statements were retained, whereas items not linked to distinguishing statements were candidates for subsequent refinement or removal. We discuss the process and results throughout the rest of the paper.

The remaining three phases of the MEASURE approach are planned for future work. These steps will involve **Using experts** to further review and refine the item pool, **Recruiting** a broad participant sample to administer the survey, and **Evaluating** instrument reliability and checking multiple forms of validity. Although the present study does not yet encompass these final phases, the Q-informed initial reduction reported here moves the instrument one step closer to completion for our undergraduate engineering leadership development instrument.

2. Methods

In this paper, we again leverage Q methodology, a mixed-methods approach that quantifies subjective viewpoints by having participants rank a shared set of statements onto a forced grid with a quasi-normal distribution [11]. Correlating participants' Q sorts reveals statements of agreement and disagreement, yielding factors that represent distinct viewpoints. The factors that emerge provide an empirical basis for interpreting beliefs and constructing engineering leadership profiles, while distinguishing statements inform the refinement of our preliminary survey item pool.

2.1 Refined concourse & data collection

This second phase of data collection was informed by four main insights from our initial data collection [5]. This includes conducting think-aloud protocols to validate the interpretability of the statements among undergraduates, revising the original Q statements as needed, and digitizing the process, thereby broadening our participant pool and ensuring we capture a comprehensive set of viewpoints on EL.

During the ten think-aloud sessions [12] (eight engineering students and two faculty), participants tested the use of a glossary to reduce confusion and support consistent interpretation of the 60 Q statements. Four think-aloud sessions were conducted while participants completed the Q-sort activity in a physical format, and the remaining six were conducted using the digitized version to refine our use of the virtual platform and work out any technical issues prior to its official release for the second round of data collection.

For digitization, the team selected the Q Method software [13] for its user-friendly online interface and ability to allow participants to complete sorts asynchronously. To recruit participants, we distributed invitations through multiple professional and academic channels to maximize reach and accessibility. Recruitment was conducted via an email sent by our university's institutional advancement office to engineering alumni, social media announcements coordinated through the university's social media accounts, LinkedIn posts, and advertising in the ASEE LEAD Division's newsletter. Upon providing consent, participants received a link granting them access to the online platform, along with instructions for completing the Q sort. A glossary defining each statement was provided to minimize any potential confusion. A total of 27 participants completed a 5-question screening survey, a presort, and a Q sort. Seventeen of the participants also completed the optional 9-question post-completion demographic survey. Fig. 1 shows a composite Q sort grid generated by the Q Method software.

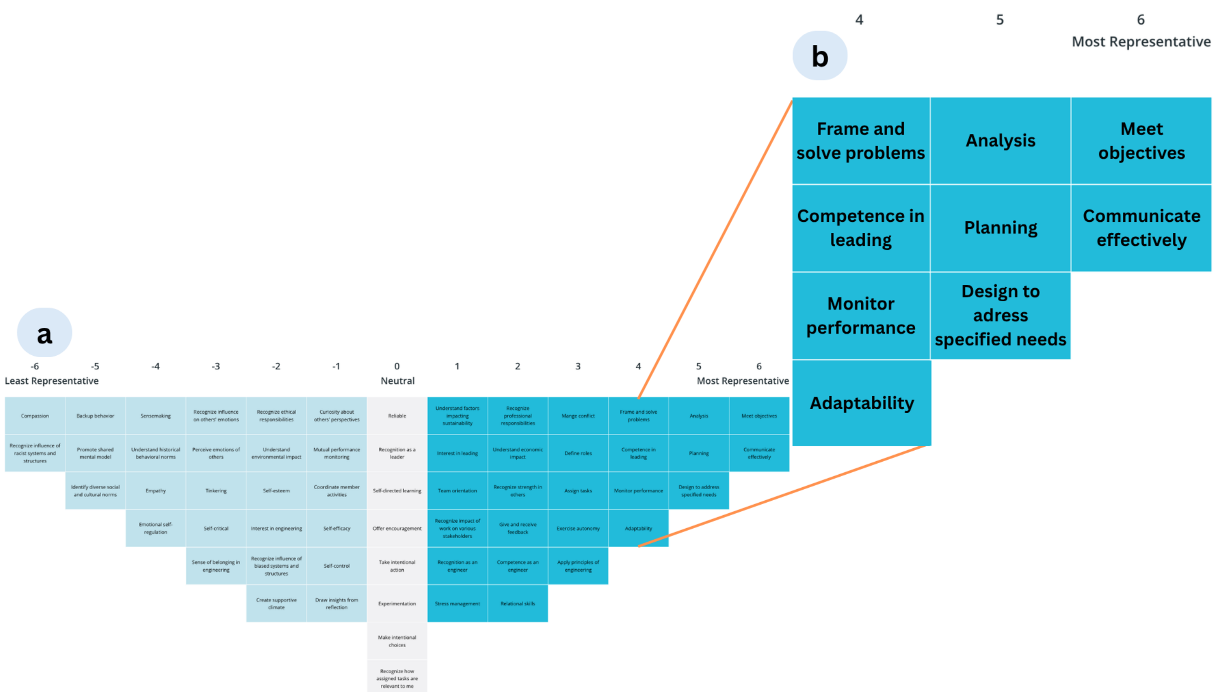

Fig. 1. (a) Example composite factor array generated by Q methodology software during data analysis. (b) Zoomed in statement of the composite factor array.

As in our pilot work [5], the 27 sorts were analyzed using the built-in analysis in KADE software [14]. A total of 24 participants significantly loaded into three interpretable factors. Each factor represents a viewpoint on effective engineering leadership situated within the constructs of the

CELD Framework. The team interpreted these viewpoints using the highest-rated distinguishing statements (most representative) and the lowest-rated (least representative). The analysis revealed three distinct viewpoints regarding the prioritization of effective engineering leadership: prioritizing technical execution, prioritizing interpersonal effectiveness, and prioritizing deliberative impact.

2.2 Leveraging Q Method Factor Analysis in Item Reduction

Following factor interpretation, we employed the distinguishing statements and consensus statements to guide the systematic reduction of the initial 60-statement concourse and corresponding survey items. Q methodology enabled us to identify which statements are unique to each factor and which are shared across them. By leveraging these statistical results, we explored four item reduction strategies to balance efficiency, content coverage, and the goals to (1) assess engineering leadership development and (2) maintain the option to assess students' developing EL profiles.

<u>Distinguishing Statements</u>

Distinguishing statements are those rated statistically different across factors at $p < .05$. Factor analysis and the retention of their distinguishing statements yielded 50 distinct statements across the three viewpoints. These statements represent the items that most effectively differentiate the three leadership viewpoints, making them highly valuable for both assessment and leadership profiling. We examined two approaches for integrating distinguishing statements into the item reduction process:

1. Keep the highest-rated distinguishing statements only

This approach retains only the statements rated most important for each viewpoint. This strategy is the most efficient in terms of item reduction, because only 14 out of the 50 statements of interest are positively rated. Additionally, by emphasizing only highly valued skills, we can optimize the capture of the most important statements according to participants. However, omitting items that capture the least characteristic of each factor could bias the instrument toward desirable skills only, thereby limiting the scale's diagnostic value. It may also reduce the sensitivity for learners who score high on some facets but low on others.

2. Keep the highest- and lowest-rated distinguishing statements

This strategy reflects both what each leadership viewpoint prioritizes and what it deprioritizes, creating a fuller contrast among factors. For assessment purposes, including both the highest- and lowest-rated distinguishing statements ensures that items representing the perceived extremes of leadership behaviors are included for each viewpoint. For profiling purposes, identifying contrasts among items allows clearer differentiation among students' leadership styles. Further, some of the skills rated least important by one factor are rated highly by another, making those items essential for discriminating among leadership patterns. Keeping both the highest and lowest-rated distinguishing statements results in the use of 30 of the 50 distinguishing statements.

<u>Consensus Statements</u>

Consensus statements are those consistently rated across factors, representing items that participants agree are desirable in an effective engineering leader. Thus, we also considered two additional reduction strategies that leverage consensus statements.

3. Include all full consensus statements with the highest- and lowest-rated distinguishing statements

Including consensus items can strengthen the instrument's measurement of foundational leadership competencies that transcend factor differences. Only two statements met consensus across the three factors; however, one of these statements also appeared as a high-rated distinguishing statement. To avoid double-counting, it was counted only once, resulting in 31 Q statements.

4. Include all full and partial consensus statements with the highest- and lowest-rated distinguishing statements

We also analyzed partial consensus (agreement between two of the three factors), which would contribute an additional 14 statements. Including both full and partial consensus statements can expand construct coverage but also increase length and obscure differences between factors.

Final Reduction Strategy

A key consideration in selecting the final reduction strategy was that we did not want to narrow the instrument's application to only profiling or only diagnostics at this developmental stage. The instrument is intended to measure engineering leadership development in undergraduate students, while retaining the option to assess their engineering leadership profile based on the strength of their alignment with viewpoints. Although one might argue that only positively rated items should be retained because they represent the behaviors perceived as most indicative of an effective engineering leader, negative distinguishing statements capture an equally informative concept, much like reverse-coded items often used in surveys. Retaining both types can strengthen the instrument's interpretive power and diagnostic utility. Therefore, to preserve meaningfulness without increasing instrument length, we used the full set of consensus statements and the highest- and lowest-rated distinguishing statements in our item reduction process.

2.3 Survey item generation

In recognition that ample work on measuring aspects of CELD already exists, we approached item generation by leveraging existing survey instruments aligned with the CELD framework, rather than generating items from scratch. The team therefore reviewed existing instruments to determine whether they could be used as is or adapted to measure aspects of CELD. In total, 14 instruments were identified (Table I). Included in this set of instruments are general and engineering leadership assessments with high potential for CELD alignment, as well as instruments targeting specific CELD dimensions. Individual items were then assessed and mapped to at least one of the 60 Q statements based on a review of their wording and intended construct, as described in the original publications. We used the team-developed glossary to maintain a consistent interpretation of statement definitions throughout the process. Two researchers independently mapped survey items to Q statements. When differences in mapping arose, the team discussed the item–statement alignment in detail until agreement was reached. Because delegation was not forced, items that did not demonstrate sufficient conceptual alignment with the CELD framework were omitted.

TABLE I

COMPILATION OF INSTRUMENTS RELATED TO THE CELD FRAMEWORK.

CELD Construct	Instrument Source	Items Extracted
Effectual Behavior	Trait Emotional Intelligence Questionnaire [15]	30
	Self-Awareness Scale [16]	54
	Perceived Competence Scale [17]	4
	Engineering & Leadership Identity [18]	11
Contextual Awareness	Personal assessment and reflection: Social and Emotional Learning Competencies (Adults) [19]	45
	Engineering Professional Responsibility Tool [20]	50
Engineering Context	Affect Toward Engineering Professional Practice [21]	30
Teamwork	Team Member Evaluation Form [22]	7
	Knowledge-Sharing Leadership [23]	67
Related Leadership Instruments	Leadership Self-efficacy Scale for Engineering Students [24]	38
	Leadership Behaviors Ranking [25]	30
	Curricular and Co-curricular Influences on Undergraduate Engineering Student Leadership [26]	22
	Leadership and entrepreneurship skills assessment instrument [27]	30
	Creating an Instrument to Measure Leadership, Change, and Synthesis in Engineering Undergraduates [28]	46

3. Results and Discussion

3.1 Participant Demographics

Participants completed two short surveys as part of this study, and responding to both surveys was optional. Those who responded represented ten industry sectors, with the largest representation from Aerospace (n = 7) and Manufacturing (n = 5). Regarding professional practice, the largest subset reported working in Project Management (n = 9). Most participants were highly experienced, with 19 participants reporting more than 15 years of engineering experience. Participants also reported substantial leadership experience, with 13 participants indicating more than 15 years in leadership roles. Participants held a variety of academic qualifications. The most common undergraduate degrees were Mechanical Engineering (n = 7), Electrical Engineering (n = 5), Industrial Engineering (n = 4), and Civil Engineering (n = 4). At the graduate level, the most prevalent degrees were MBA (n = 6) and Systems Engineering master's (n = 4). Geographically, participants were primarily located in the Southern (n = 8) and Midwestern (n = 5) regions of the United States. Regarding leadership development, most participants reported having some prior leadership training and a strong or moderate emphasis on leadership development in their organizations. In terms of demographic characteristics, 13 participants self-identified as Hispanic, and 13 identified as White. The gender representation of those who answered was four women and thirteen men.

3.2 Q Statement Concourse Reduction

As described above, to reduce our initial set of statements, we used the distinguishing and full-consensus statements associated with each of the three viewpoints (i.e., an effective engineering leader prioritizes technical execution, an effective engineering leader prioritizes interpersonal effectiveness, and an effective engineering leader prioritizes deliberative impact) to compile a master list of statistically significant statements. This reduced the initial concourse of statements from 60 to 31. The reduction was roughly proportional across the CELD dimensions (Fig. 2). A complete list of the 31 retained Q statements is available in Table II.

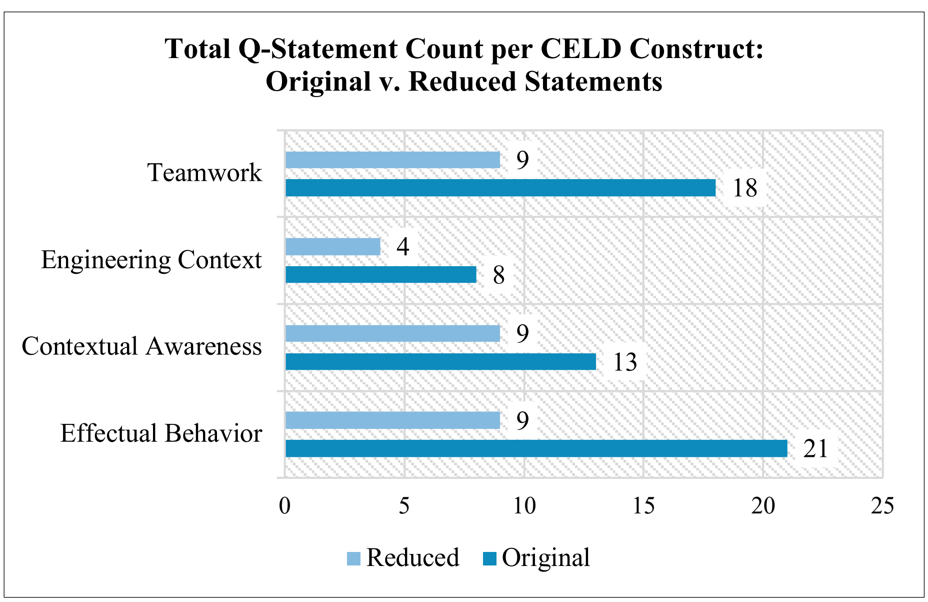

Fig. 2. Number of Q statements across CELD dimensions before and after reduction

TABLE II

NUMBER OF INSTRUMENT ITEMS RETAINED PER STATEMENTS OF CELD CONSTRUCT

CELD	Statement	Instrument Items
CA	Recognize ethical responsibilities	28
CA	Recognize impact of work on various stakeholders	11
CA	Understand economic impact	2
CA	Empathy	9
CA	Identify diverse social and cultural norms	11
CA	Understand factors impacting sustainability	5
CA	Recognize influence of biased systems and structures	8
CA	Compassion	7
CA	Recognize influence of racist systems and structures	0
EB	Competence in leading	11
EB	Stress management	5
EB	Take intentional action	8
EB	Exercise autonomy	1
EB	Make intentional choices	5
EB	Perceive emotions of others	1
EB	Self-efficacy	6
EB	Emotional self-regulation	11
EB	Recognition as a leader	3
T	Communicate effectively	10
T	Planning	5
T	Team orientation	16
T	Assign tasks	4
T	Create supportive climate	16
T	Self-directed learning	7
T	Sensemaking	3
T	Mutual performance monitoring	5
T	Promote shared mental model	16
TM	Design to address specified needs	7
TM	Frame and solve problems	9
TM	Tinkering	14
TM	Experimentation	3

3.3 Instrument Survey Item Reduction

To reduce the preliminary item pool, the 464 survey items extracted from the 14 instruments were organized in Excel. Once the final set of 31 distinguishing and consensus Q statements was identified, this spreadsheet served as the basis for filtering the item pool. Survey items were retained when they aligned with at least one retained Q statement and removed when they were associated only with Q statements eliminated from the concourse. Items that did not demonstrate clear alignment with a Q statement were also removed from candidacy. The resulting spreadsheet provided a structured record of the item-reduction process, including each item's source instrument number, original item number, item text, original construct, mapped Q statement, CELD construct, and reduction decision. Table III illustrates the organization of this dataset.

TABLE III

EXAMPLE OF DATA SET STRUCTURE

Instrument #	Item #	Original Item Text	Original Construct	Q Statement	CELD Construct	Reduction Decision
SI:1	4	I am a confident person	Confidence	Self-esteem	Effectual Behavior	Reduce

This process narrowed the pool from 464 original items to 247 retained items. However, this reduction in item count was not uniform across the source instruments. Some instruments retained most of their original items (e.g., Engineering Professional Responsibility Tool: 50 → 44), while others were reduced significantly or eliminated entirely (e.g., Perceived Competence Scale: 4 → 0). Table IV presents the number of item reductions for each instrument. Instruments with very small or large percentages of items retained may indicate instruments that could be removed (e.g., Perceived Competence Scale) or retained entirely (e.g., Engineering Professional Responsibility Tool). Our ultimate goal is to determine the minimum set of complete scales for individual constructs or entire instruments required to fully measure the CELD dimensions.

As an initial evaluation of the reduction outcomes for instrument development, we reviewed the retained items to determine whether any conceptual elements of the CELD framework were lost during reduction. Fig. 3 shows the count and percentage of both original and retained items per CELD construct relative to their grand total.

TABLE IV

RESULTS OF ITEM REDUCTION FOR EACH INSTRUMENT

CELD Construct	Instrument Source	Item Reduction (Original→Reduction)
Effectual Behavior	Trait Emotional Intelligence Questionnaire [15]	30 → **13**
	Self-Awareness Scale [16]	54 → **3**
	Perceived Competence Scale [17]	4 → **0**
	Engineering & Leadership Identity [18]	11 → **0**
Contextual Awareness	Personal assessment and reflection: Social and Emotional Learning Competencies (Adults) [19]	45 → **23**
	Engineering Professional Responsibility Tool [20]	50 → **44**
Engineering Context	Affect Toward Engineering Professional Practice [21]	30 → **20**
Teamwork	Team Member Evaluation Form [22]	7 → **5**
	Knowledge-Sharing Leadership [23]	67 → **42**
Leadership	Leadership Self-efficacy Scale for Engineering Students [24]	38 → **22**
	Leadership Behaviors Ranking [25]	30 → **16**
	Curricular and Co-curricular Influences on Undergraduate Engineering Student Leadership [26]	22 → **12**
	Leadership and entrepreneurship skills assessment instrument [27]	30 → **19**
	Creating an Instrument to Measure Leadership, Change, and Synthesis in Engineering Undergraduates [28]	46 → **28**

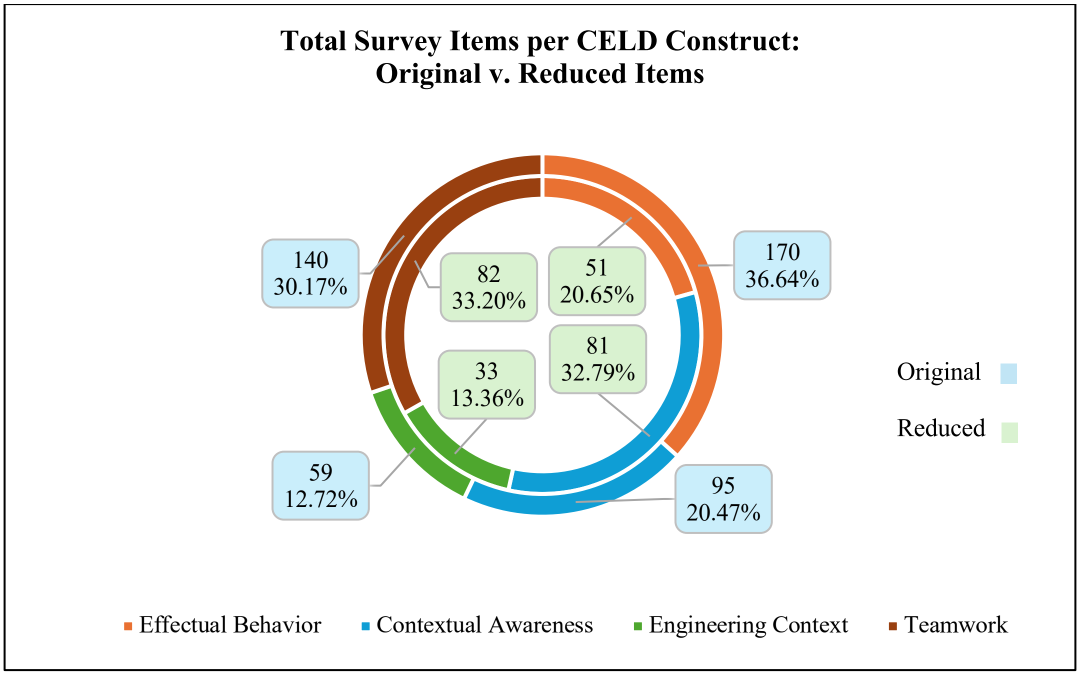

Fig. 3. Count and percentage of items in each CELD dimension before and after survey item reduction.

The review of the number of items retained in relation to the CELD framework and distinguishing statements revealed important patterns. All four CELD constructs remain represented, and the inclusion of both the high- and low-rated distinguishing statements allowed for each construct to retain multiple items. The process also revealed that items were unevenly distributed across statements, and one statement had no assigned items, as shown in Table IV. This uneven distribution across Q statements points to potential pools of items worth considering for further reduction (e.g., "recognize ethical responsibility") and potential areas where additional instruments may be needed (e.g., "Recognize influence of racist systems and structures").

4. Insights Informing Future Work

Based on this work, the forthcoming steps will guide continued item reduction and refinement.

- We plan to further reduce the list of Q-statements by identifying and combining statements that may be too closely related (e.g., Biased systems/racist systems).

- A systematic review will be conducted to identify additional survey instruments related to the 31 statements, with the goal of identifying additional items that may strengthen alignment with each statement, fill gaps, and support validation.
- We aim to rely on the fewest possible instruments, standardize wording across retained items, and explore which survey format and item style will be most conducive to our intended applications.
- Finally, we plan to reduce the number of items per construct, with a preference for retaining four to six items per Q statement to improve conciseness and further test item homogeneity [9], thereby eliminating redundant or weakly aligned items.

5. Conclusion

This study moves us a step closer to the development of a transferable undergraduate engineering leadership development assessment. Following MEASURE [6] for a systematic approach to instrument development, along with the strong theoretical foundation of the CELD framework and the iterative use of Q methodology, enabled us to characterize three emerging engineering leadership perspectives and demonstrate the value of distinguishing and consensus statements as a filter for item reduction. Through this process, we reduced an initial pool of 464 to 247 instrument items. These findings reaffirm the integration of MEASURE with Q methodology as an effective tool for item reduction in instrument development. While further work is required, including the last three steps in the MEASURE approach, the present study lays a foundation for creating an EL instrument that assesses undergraduate student leadership development, aligns with emerging definitions and models of EL development, and is sufficiently transferable across programs. Ultimately, this work contributes to the broader goal of advancing engineering leadership education through evidence-based, transferable assessment practices.

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