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Technical Standards in Engineering Education: Present Challenges Across Professional Sectors

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Abstract

The need for technical standards that accurately represent today's growing infrastructure, electrification efforts, and enhanced digitalization touches all sectors of the engineering workforce and beyond. However, engineers, students, and educators lack training in the development and implementation of technical standards. These challenges are expressed in technical committee meetings, in office rooms after hiring a new engineering intern, and by educators across engineering disciplines seeking ABET (Accreditation Board for Engineering and Technology, Inc.). We hypothesize that the technical standards challenges faced by the collective engineering profession are similar. A survey about the importance of and challenges presented by technical standards was completed by participants (N = 201) from multiple disciples, educational levels, and backgrounds across the United States. This paper analyzes the written responses provided in response to the survey (N = 149). Participant responses highlight seven technical standards challenges: education, awareness, appreciation, accessibility, interpretation, application, and logistics. Participant responses highlight five reasons technical standards education is important: safety/best practice, practical application, expectations of the profession, employment and business, and foundation/career development.

Introduction

The development, use, and education of technical standards have blossomed in the past few decades. While these documents bring great order and structure to the engineering field and beyond, major challenges persist for users, educators, and students.

In general, technical standards are agreed-upon procedures, tests, and protocols established in a written format through consensus among a group of interested and expert individuals on a particular topic. This is the definition that will be used in this paper. However, it is well known that the phrase "technical standards" has a plethora of interpretations depending on the context of the situation and the parties involved. There are company standards that are primarily for internal use, "de jure" standards that are formally published by standards organizations, agreed-upon common practices (e.g., eating with one's mouth closed) that the general public refers to as a “standard”, and many more [1]. The ambiguity in the definition of the word "standard" and engineers' contextual interpretation and historical use of the word adds to the challenge of studying, discussing, and applying technical standards.

In addition to the complexity of the name, a large challenge is present in the lack of technical standards education research and engagement despite the known strategic value to society and industry [2]. In some companies, technical standards education and engagement are shunned. In others, it is seen as a political process with an indeterminate outcome [3]. Therefore, employees are discouraged from participating in the technical standards development process or are required to sacrifice their personal time to volunteer for such efforts [2]. This deterrence from participation in the standards development and standardization process creates additional educational challenges for professionals and students.

A variety of technical standards challenges are present in the literature. For starters, academia is expected to provide basic technical standards education rather than supplement the training provided in industry co-ops and internships [4]. Educators struggle to provide technical standards education due to the overloaded higher-education curriculum [2] and the need to customize existing content for discipline-specific courses [5]. Much of this burden (including the maintenance, purchasing, and education of technical standards) falls on academic librarians who are in short supply. Little to no attention is given to educating graduate students on technical standards [2]. Due to these known challenges, efforts have been made on behalf of multiple organizations to provide free or low-cost access to technical standards education. A list of these organizations and resources is provided in [6], a technical standards webliography developed by Assistant Professors of Library Science Margaret Phillips and Sarah Huber. Additionally, technical standards education faces industrial challenges due to the increased technological complexity and rapid standards evolution [2]. Examples include complex processes like additive manufacturing and vehicle electrification efforts that demand new technical standards and revisions to existing ones.

Such challenges are likely to ebb and flow with time and vary greatly with respect to focus areas and individual needs. However, the need for technical standards education is rising. Unfortunately, it can take many years for professionals unfamiliar with technical standards to become fully proficient when relying on industry to provide such education [2]. Therefore, technical standards education must be deployed in the United States with higher quality and frequency than in the past. To ensure this happens a deeper understanding of the current challenges facing technical standards education is necessary.

Methods

This paper is the second in a project aimed at providing technical standards education to undergraduate engineers. It analyzes the free response data collected from the survey published in [7]. Appropriate human subjects' approval was obtained through the [IRB-23-07511-XM].

Survey

A Google Forms survey was disseminated: (1) to gauge the current relationship between technical standards education and the engineering profession as a whole and (2) to gather feedback on a solution proposed to tackle multiple challenges surrounding technical standards education at the undergraduate level. The snowball effect, a common phenomenon in which a situation (i.e., survey distribution) increases at a faster and faster rate over time, was employed to survey multiple engineering organizations, companies, technical societies, and individuals from October 2022 to March 2023. The survey was primarily distributed in the mid-western portion of the United States with increased distribution in the state of Tennessee where the authors are located. The survey is known to have been accessible outside of the country's borders due to the distribution method. However, the survey was not intentionally shared outside the country and the distribution materials expressed that the study focus was within the United States.

The survey was shared primarily via email, discussion platforms, and business card-sized handouts that included a QR code link. No limitations were put on who could complete the survey and no compensation was offered for completing the survey. Two hundred and one people completed the survey. One hundred and forty-nine participants completed one or more of the open-ended questions. The authors do not know the response rate for the survey, nor do they have data as to the number of individuals with direct or indirect access to the survey. From the authors' estimates, they directly shared it with 400 individuals, 30 organizations, and 5 public platforms. The authors also received ten email requests to share the survey via public platforms and approved them all. With the assumption that 10 individuals from each organization and 20 individuals from each public platform viewed the survey (clicked on the link), the response rate would be roughly 20% as calculated in Equation 1. The authors believe this is a conservative estimate.

$$\frac{200}{400 + 30*10 + (5+10)*20} = \frac{200}{1000} = 20\% \qquad \text{Equation (1)}$$

The survey included a mixture of multiple-choice and open-ended questions. For this paper, the following five open-ended questions were considered:

- What are your biggest challenges with respect to technical standards and technical standards education?
- Which technical standards or standards organizations are most important to know about for your industry?
- Why is technical standards education at the undergraduate engineering level most important?
- What particular aspects of technical standards content do you believe should be included in the curriculum?
- Is there anything else you would like us to know?

A full copy of the survey (including multiple-choice questions), additional survey details, and an analysis of the multiple-choice questions are published in [7]. The authors elected to separate the data analysis into two papers for two reasons: timing and paper length. Splitting up the analysis allowed for dissemination of the multiple-choice analysis a year earlier; it did not depend on coding which the authors anticipated would take 3-6 months to complete and 3-6 months to write and publish. Second, separate papers allowed the authors to go into additional depth of analysis while limiting paper length.

Data Analysis

The authors performed a qualitative analysis of the data using a combined content analysis [8], [9], grounded theory [10], [11], [12], and thematic analysis approach [13], [14], [15]. Data was deidentified and each participant was assigned an identifier for their responses. The analysis was transferred and performed in Microsoft Xcel. No qualitative analysis tool was used for the study as it focuses on frequencies.

Formation of Thematic Categories

The data was cleaned and all non-responses (i.e. blanks, N/A, no comment) were removed from the dataset resulting in 149 participant responses. Responses were read line by line, but not coded. Initial thematic categories were independently generated by both authors. There was no limit to the number of analytical categories each author could create.

First Cycle Coding

The authors combined, discussed, and edited their thematic categories and formed an agreed-upon list of higher and low-order themes. The high-order themes are Challenges and Importance. The lower-level themes, respectively, were Education, Awareness, Appreciation, Accessibility, Interpretation, Application, and Logistics; and Safety/Best Practice, Practical Application, Expectations of the Profession, Employment and Business, and Foundation/Career Development.

The dataset was then independently coded by Researcher 1, who has more experience coding data, in its entirety. Each identifier was broken down into one or more codes. Those codes were then linked to one or more analytical categories. The frequency of identifiers associated with the analytical categories was then generated into a frequency table. This frequency table was an intermediate and is not provided in the paper.

An example of the above process is described here. Participant X's responses were assigned “Identifier 1." These responses (i.e., written words, phrases, sentences) were coded. For example, the text "Cost. Understanding licenses. Understanding applications." was broken down into three codes: "Cost." "Understanding licenses." and "Understanding applications." These codes were then linked to the respective analytical categories: Accessibility, Logistics, and Application. In this case, each code is simplistic; therefore, each code was associated with one analytical category. Each of these three analytical categories increased by a frequency of one following the analysis of this text from Identifier 1. In the event additional text was associated with Identifier 1 (i.e., the participant answered more than one question), the same process was repeated. An analytical category's frequency count was prevented from increasing by more than one count per Identifier regardless of how many codes were assigned. For example, a respondent whose paragraph response was coded for five different education challenges only increased the Education analytical category by one.

Second Cycle Coding

The authors re-grouped to discuss the first cycle coding. A second pass through the data was conducted to search for additional themes (No additional ones were evident.) and to confirm that the identified themes worked with the individual codes and the entire dataset (The authors confirm this.). The authors agreed and termed this the saturation point between the data and the analytical categories. The final frequency table was generated and is provided in Table 1.

Analysis

Additional frequency tables were derived from the main frequency table by sorting the codes (which remained linked to the identifiers) according to four participant identifiers: Engineering Classification, Title, Level, and Professional Sector. The authors felt these frequency tables were tough to visualize. Therefore, graphs were created representing the respondent frequency percentage. Tables of highest interest (Level) are presented in the results section. The other tables (not participant-identified, Engineering Classification, Title, and Professional Sector) that were generated and utilized in the analysis are provided in Appendix A.

Analytical Category Descriptions

The below descriptions for each higher- and low-order theme evolved as the authors coded and analyzed the data. They are not all-inclusive but did aid immensely in ensuring consistency in coding and help the researchers to align their understanding of the thematic categories.

Themes	Description
Challenges	This high-order theme represents the various obstacles respondents report when engaging with technical standards and technical standards education. This is directly related to the free-response questions that were asked.
Education	This low-order theme represents challenges related to education. It encompasses education at the university level, barriers to learning, content-related issues, and the lack of resources to promote an active learning environment. Comments that referenced educational challenges impacting their career path were also included here although the responses did not always state if the challenge was academic. Multiple participants reported not completing a formal education in engineering. It should be noted that the lack of accessibility to standards was coded solely as "Accessibility" unless there was mention of a specific educational challenge (e.g., lack of academic funding for librarians to purchase standards).
Awareness	This low-order theme represents challenges related to the concept of technical standards and the document itself (e.g., unable to find it when searching online). It also includes the challenges associated with the breadth of and constantly evolving nature of technical standards. Examples of reported challenges include being unaware of new standards, the latest revisions, or the adoption of a standard/part of a standard by a standard development organization.
Appreciation	This low-order theme represents challenges related to understanding the value of technical standards and their organization and structure. Additionally, this category included the distillation of technical standards information to those around oneself. An example would include a respondent stating they tried to teach their students why standards were important and worth learning. Responses varied from the physical appearance of the document (e.g., long, boring) to the text or tone within it (e.g., touch to grasp), to the lack of interest surrounding standards.
Accessibility	This low-order theme represents challenges related to physically accessing technical standards, the preferred version, or the latest version. Financial barriers were also included here.
Interpretation	This low-order theme represents challenges related to identifying the correct technical standard for a particular application. It also encompasses understanding if the technical standard that one has is relevant to the situation at hand, and if so, to what extent it is relevant. Lastly, it includes

	inferring meaning from the written words within the document to determine what the standard includes or does not include.
Application	This low-order theme represents challenges related to carrying out the actions associated with the technical standard one has successfully identified as relevant and interpreted the meaning behind. It also includes analyzing how the setup or test procedure may need to be altered for different situations.
Logistics	This low-order theme represents challenges associated with the politics and bureaucratic systems behind technical standards. It also involves standards development organizations and technical standards task forces/work groups/committees. Lastly, it includes specifics about the organization, naming, and structure of the technical standard document itself.
Importance	This high-order theme represents the reasons participants stated technical standards education, inside and outside of the university setting, is important. This category is directly related to the free-response questions that were asked.
Safety/Best Practice	This low-order theme represents the value technical standards provide from a safety and consistency standpoint. It encompasses comments about adhering to industry recommendations, existing policies and procedures, and following ethical best practices.
Practical Application	This low-order theme represents the need for individuals to have a thorough knowledge and grasp of technical standards so that they can put them to use in real-life applications (e.g., senior design projects, internships, industry). In most cases engineers were listed as the subjects in these responses; however, multiple respondents stated people in general should know about standards.
Expectations of the Profession	This low-order theme represents the statements that technical standards education and experience are requirements for engineering students and working engineers. Multiple responses affirmed that technical standards knowledge is a critical component of the engineering profession and part of the core identity of an engineer.
Employer/Business	This low-order theme represents the benefits individuals with technical standards knowledge and experience provide their employer(s) and the world of business. Additionally, this category includes the negative repercussions associated with a lack of technical standards knowledge. The inverse was not stated in any responses, but it would have been included here if it was; this note is added to show the lack of conflicting statements coded in this category. Statements ranged from describing benefits such as

	saving time and money to helping with strategic employee placement to technical decision-making.
Foundation/Career Development	This low-order theme represents the statement that technical standards education is fundamental to an individual's career in the engineering field. It forms a base knowledge that other concepts are built upon.

Table 1: Descriptions of Higher- and Low-order themes.

The authors were challenged with coding a plethora of comments that mentioned “reading” and “understanding” standards as a Challenge when determining the low-order themes. It was assumed that all participants completing the survey were able to read the physical text in a technical standard. Therefore, the assumption was made that “reading” referred to standard interpretation, relevance, and identification. Each code that referred to “reading” a standard was therefore coded as Interpretation. Similarly, references to “understanding” were coded as Interpretation after referencing a few definitions and settling on “to perceive the intended meaning of" or “to interpret or view something in a particular way." This coding challenge is highlighted here for transparency, but also because the authors want to call attention to the struggles researchers face when studying technical standards as the engineering community and public struggle to properly express themselves when talking about standards. The engineering community needs to improve its technical standards communication if it expects students and new engineers to learn quickly.

Results

Ninety-three percent and 89% of participants reported high-order Challenges and Importance of technical standards and technical standards education respectively, as listed in Table 2. Table 2 provides the frequency count, N, for each high-order and low-order theme. The frequency percentages are provided in parentheses. For the high-order themes, these values were calculated by taking the high-order theme frequency count divided by the total number of Identifiers (149, one per participant) following the cleaning of the data. For the low-order themes, these values were calculated by taking the low-order theme frequency count divided by the high-order theme frequency count. The example responses provided were randomly selected from the compiled code. The identifications provided for the example responses are associated with the level of the Identifier associated with the code. Identification of the level was selected for Table 2 over other categories based on the patterns the authors observed in the data. This is expanded upon in the Discussion section.

High Order Theme	N (%)	Lower Order Theme	N (%)	Example Response
Challenges	138 (92.62%)	Education	65 (43.62%)	"I saw how they are used during my internship and was not aware of their role during the times I was taking courses." - Student

		Awareness	40 (26.85%)	"What are they [standards]?...No idea because I haven't been exposed to many." - Student
		Appreciation	12 (8.05%)	"I don't think curricula should be overly vocationally focused - those courses were the least intellectually stimulating and least relevant to my career." – New Hire (0-2 years)
		Accessibility	45 (30.2%)	"Knowing which ones exist; having access to standards while I'm not affiliated with a big organization." - Early Career (3-5 years)
		Interpretation	43 (28.86%)	"Finding the relevant standard." - Senior (20+ years)
		Application	38 (25.5%)	"Understanding the applicability of standards as well as their limitations." - Early Career (2-5 years)
		Logistics	33 (22.15%)	"Getting participation by individuals who are not employees of affected manufacturers." - Senior (20+ years)
Importance	133 (89.26%)	Safety/Best Practice	26 (17.45%)	"Everything related to health and safety, environmental standards...Knowing how to engineer according to standards helps create a better engineering environment for everyone. " - New hire (0-2 years)
		Practical Application	63 (42.28%)	"How to properly use them in 'real life.'" - Student
		Expectations of the Profession	61 (40.94%)	"Engineers need to know how to use standards to do their job." - Senior 20+ years
		Employer/Business	30 (20.13%)	"Any engineers who go into industry need to engage with technical standards, getting used to them and the systems around them can help a lot to prepare for a career." - Early Career (0-2 years)
		Foundation/Career Development	43 (28.86%)	"It lays the foundation for what is expected from engineers as soon as they exit academia and enter into the real world of engineering

application and technical standards.
" - New Hire (0-2 years)

Table 2: Table of High-Order and Low-Order Themes' respective frequency counts and percentages. A randomly generated response taken from the coded data is provided as an example of the data the authors analyzed.

Higher Order Theme Comparison: Challenges and Importance

Participant frequency percentages for Challenges and Importance vary based on the analysis category (e.g., level, professional sector). The most significant gaps between Challenges and Importance were reported, respectively, in Administrators (33% and 50%), Executives (30% and 60%), and Intern/Co-ops (64% and 45%).

When analyzed by level in Figure 1, the data showed that the frequency percentage of Challenges reported increases for Students through New Hires (0-2 years) of experience. Then there is a decline in Early Career (2-5 years) followed by an increase in Challenges reported by Mid-Careers (6-20 years) and Seniors (20+ years) who have increased years of experience. In contrast, when analyzed by level, the data shows that the frequency percentage for high-order theme Importance decreases for Students and Intern/Co-ops. This is followed by an increase for New Hire (0-2 years) and a decline for Early Career (2-5 years). The Importance frequency percentage then increases through Senior (20+ years, overtaking the high-order theme Challenge frequency.

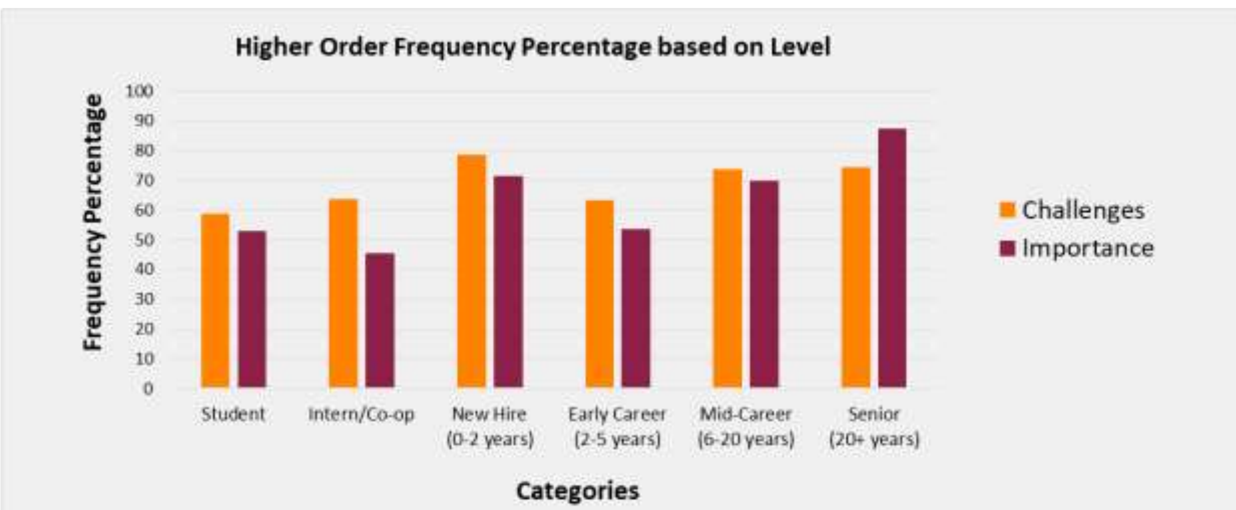

Figure 1: Free response high-order frequency percentage from survey respondents based on level.

Low-Order Theme 1: Challenges

When analyzed by level, as represented in Figure 2, Students reported Education (41%) with the highest frequency while Intern/Co-op reported Application (36%) and Logistics (36%). Mid-career (6-20 years) and Seniors (20+ years) report decreased frequency percentages in most Challenge categories compared to other levels. Additionally, their frequency percentages appear to be similar except for Interpretation, where Mid-Career (6-20 years) is 15% higher (30% compared to 15%). The Challenges engineers face change with their level of experience.

It is worth noting that Appreciation, while it was reported with far less frequency than the other categories, was included due to the clear description of it. The other option, categorizing these responses as “Other” was rejected as it would hide valuable information.

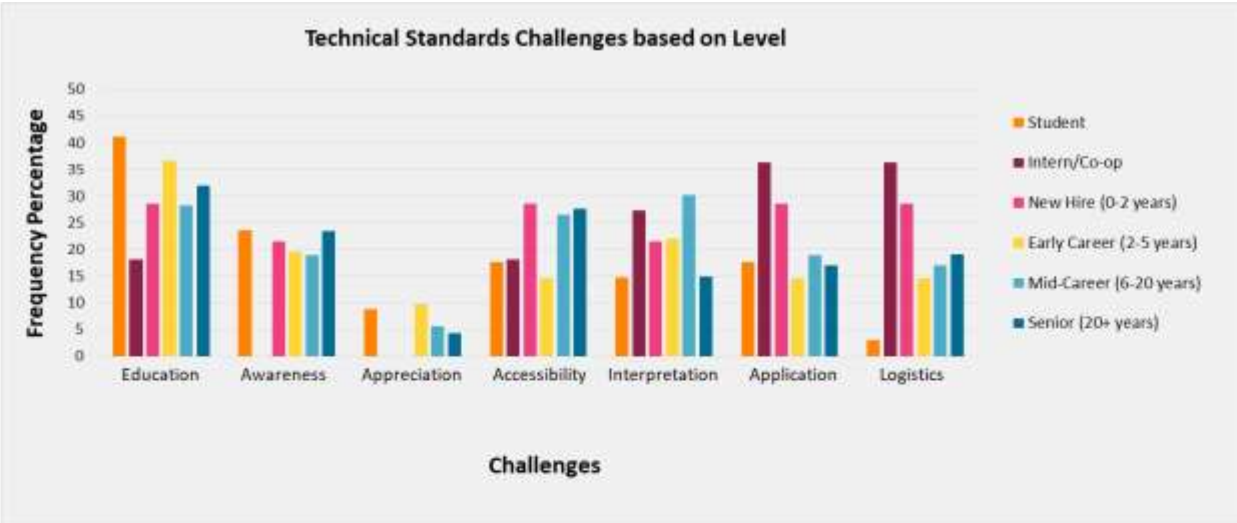

Figure 2: Free response low-order frequency percentage for high-order Challenges based on level.

Low-Order Theme 2: Importance

When analyzed by level as a collective unit, as represented in Figure 3, Practical Application and Expectations of the Profession were reported with the highest frequency. There is a large decrease in the frequency percentage of Students who reported Expectations of the Profession as important compared to all other levels. Students and Seniors (20+ years), two groups that are frequently surrounded by and working with students and young engineers, reported Foundation/Career Development with the highest frequency. Seniors (20+ years) and New Hires (0-2 years) reported employment and business as having the highest frequency percent at 28% and 21%, respectively. While seniors are aware of the business aspect of the company, new hires tend to receive formal and informal education on this topic during the onboarding process in their first year. Seniors (20+ years) reported Safety/Best Practice at a higher frequency (23%) than the other classifications by level.

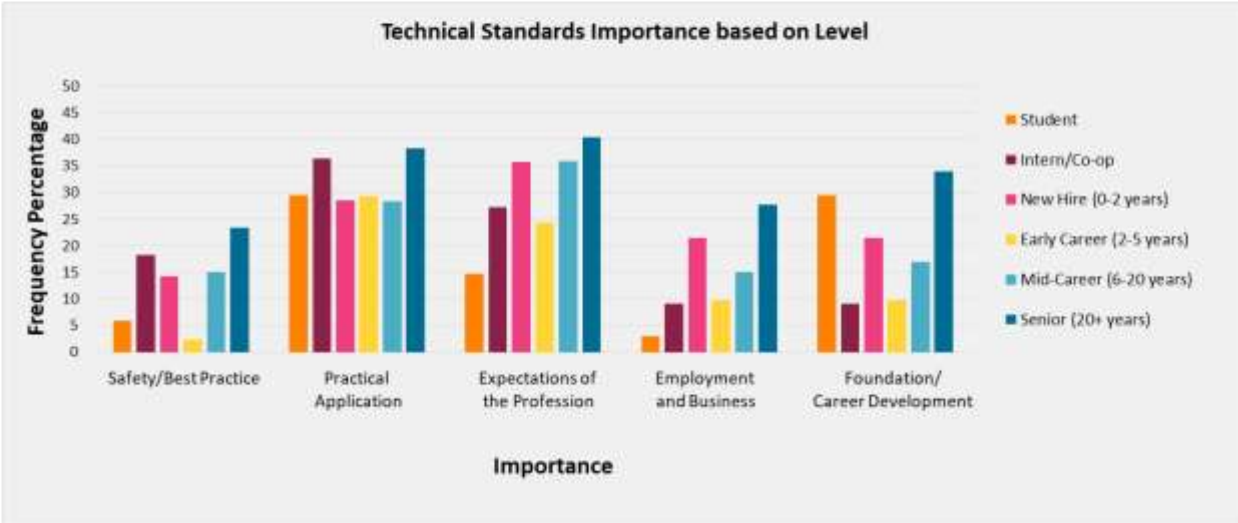

Figure 3: Free response low-order frequency percentage for high-order Importance based on level.

Discussion

The data provides great insight into the encountered Challenges and Importance reasoning engineers and non-engineers report for technical standards and technical standards education. Two notes of particular interest are the lack of student awareness of technical standards and the change in the types of Challenges and Important reasons faced with years of experience.

<u>Lack of Awareness:</u> Students are unaware of the extent to which technical standards are used or required by the profession. This is evident by the decrease in their reported frequency percentage for expectations of the profession (Figure 3), which is reported with nearly three times the frequency by Seniors (20+ years) as an important reason for technical standards education.

The high-order trends listed for Challenges and Importance based on level (Figure 1) reinforce this. The data reports an increasing trend in Challenges and a decreasing trend in Importance reported from Students through Intern/Co-op. As students get more experience with technical standards through classwork, senior design, internships, co-ops, and their first job, they become aware of more and more challenges; however, their opinion of the Importance of technical standards begins to decrease. The data collected in this study suggests that there then comes a turning point during the first few years of employment, in which New Hires (0-2 years) report fewer Challenges and an increased Importance for technical standards. Additional studies need to be conducted to determine when this change occurs (e.g., first few months of employment, after the onboarding phase, 1-2 years in).

As Early Career (2-5 years) engineers gain years of employment, the frequency percentage of reported Challenges rises. This frequency percentage potentially levels off as shown by a similar value (74%) for both Mid-Career (6-20 years) and Seniors (20+ years); however, more data (e.g., more participants, breakdown by years of experience) is needed to confirm. Seniors (20+ years) report frequency percentage levels similar to that of Intern/Co-op and New Hires (0-2 years). The view that technical standards and their respective education are important continues to increase with years of experience. Eighty-seven percent of Seniors (20+ years) reported reasons why standards are important.

The idea is further reinforced by the shifting analytical categories reported by increasing levels (i.e., more years on the job). First, the trend for reasons of Importance seen in the overall data is largely apparent and is reflected in the analytical category Expectations of the Profession when analyzed based on Level. As engineers gain experience, the types of technical challenges they face change, as does the number of challenges they face and their respective knowledge about them. The free-response data suggests this is due to the changing awareness levels and use of technical standards.

This data is additionally reinforced by analysis of the multiple-choice [7]. Students' need for basic technical standards education is stressed in the high number of respondents advocating that such education be taught in the undergraduate curriculum. It is also supported by the increasing shift of responses towards "strongly agree" for the statement "I would recommend this course to my XXX." as the blank XXX increases from generally older agreed groups (e.g., colleagues) to younger aged groups (e.g., students).

<u>Change in Challenges with Experience:</u> With experience, the primary Challenges reported generally increase and change. This is first evident in the increase reported by Students to Intern/Co-ops in the four Challenges on the right-hand part of the graph in Figure 2. There is a similar shift for New Hires (0-2 years). However, in Early Careers (2-5 years) there is a shift back towards Education as the primary Challenge. Mid-Careers (6-20 years) and Seniors (20+) report a similar frequency for all categories except Appreciation. Logically, this makes sense, as many senior engineers are mentoring younger engineers or managing a team of younger individuals. Their role in the world of technical standards spans a range of challenges depending on their assigned tasks.

<u>Change in Importance Reasons with Experience:</u> Changes are also seen in reported technical standards Importance with experience at different levels. Students are primarily focused on the Expectations of the Profession, as are the other Levels. However, major spikes in Importance are present for New Hires (0-2 years) and seniors (20+ years) for Employment and Business and Mid-Career (2-5 years) with practical application. These changes are also logical as the use of technical standards and relative Importance to the individual engineer will change at different Levels. New hires and mid-career individuals are likely to be more business-focused regarding progress in their professional careers. At the same time, seniors (20+ years) are more likely to focus on safety/best practices to provide quality, sound engineering decisions to maintain their positions within the company.

The authors propose the existence of a hierarchical structure of challenges, as depicted in Figure 4. While coding the data, it became clear that participant responses correlated with their knowledge of technical standards. Divisions of challenges arose and were segmented into challenge bands as represented by the seven sections. In this context, challenge bands are defined as generalized challenges that can be distinguished from one another. Through the blurred lines, the graph intends to indicate that the boundary of each band is not rigid. Reflection of this in the survey is shown through participant responses who list more than one challenge in challenge bands that touch each other (e.g., education and awareness, application and interpretation). The thicker white line that divides the top and bottom half represents a stronger boundary that was present in the data. If listing multiple challenges, respondent answers generally fell above or below the line rather than transversing the line.

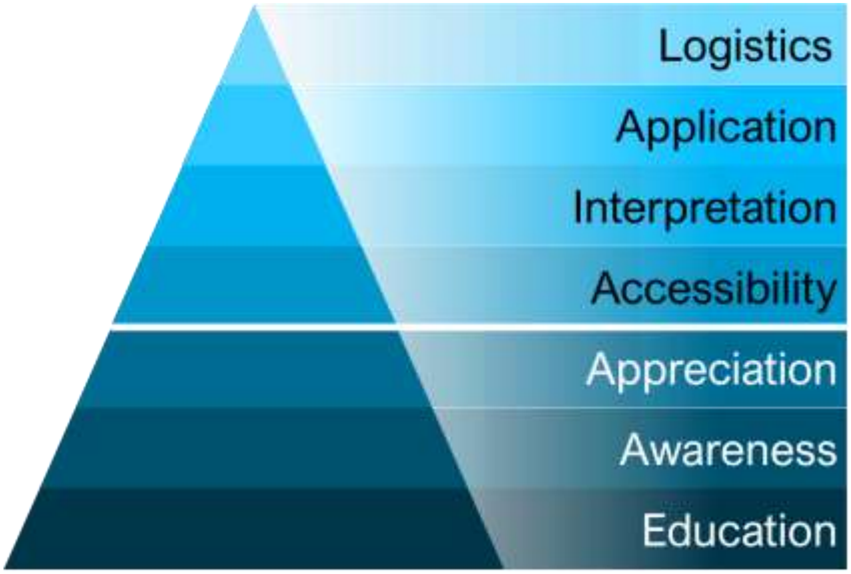

Figure 4: Proposed diagram of hierarchical structure within technical standards education. The white line indicates a potential cognitive separation aligned with Bloom's Taxonomy of Higher Orders of Thinking.

The challenge bands are related to technical standards knowledge. Individuals with less experience are unaware of the challenges plaguing more experienced engineers. As they gain experience and are increasingly exposed to standards through "on-the-job training," the challenges they report change, as does their view of the Importance of standards for engineers. This is shown in the data presented in the paper. Similar hierarchical structures are present in other areas that require a heavy hands-on application, like weightlifting and boxing.

Two ways these challenge bands were identified include direct references – when the respondent identified the challenge band and their educational level – and indirect references – when the respondent's statement identifies a challenge band, and their educational level is easily inferred or confirmed. An example of each is provided below.

Direct Reference:

> *"In my experience going into industry right after graduation, I didn't have the mentors to walk me through standards education. It is important to give students these tools so they can know what to look for and where if they are put in a similar position."*

Indirect Reference:

> *"Finding and keeping track of all applicable standards and their current version. Then reading/digesting content if it is a new standard not used before."*

The direct reference identifies the challenge gap: awareness. The individual was not aware of what to look for or where to look for technical standards information. It can be inferred that this was due to a lack of education (the challenge band next to awareness); as the respondent states, the challenge was not having mentors to provide the desired education. In addition to identifying the knowledge band, the respondent also alludes to their educational/experience level, stating "right after graduation."

Contrastingly, the indirect reference does not directly comment on a challenge band. "Reading and digesting content" could allude to interpretation, application, or both. By mentioning that multiple versions of the standard exist and that there is a need for organization, the respondent also described a logistical challenge. These three challenges – interpretation, application, and logistics – all touch each other. The phrase "finding…all applicable standards…" may be interpreted as awareness or accessibility. It is tough to determine which, but what is evident is that this response and comment, if coded as awareness, is dissimilar to the direct response. It became apparent during coding (and was later confirmed) that responses that used challenge band titles or their synonyms generally came from students, while responses like the indirect example referenced above were common to individuals well-versed in technical standards.

With knowledge of the changing landscape of challenges students face compared to experienced engineers, engineering librarians work with university faculty to develop content and training to address these challenges. Additionally, by understanding challenge bands, librarians and educators gain insight into additional challenges a student may face when submitting a specific request. For example, a student who complains that the university does not have access to a specific standard, may not be aware that multiple similar/identical technical standards exist or that previews of specific technical standards are available online. This insight can help librarians to ask better-targeted questions and ultimately better support the student.

Limitations and Future Work

A large need exists for technical standards education research and involvement in the technical standards and standardization process. The research presented in this paper was intentionally intended to provide insight into a specific project. As a result, the questions and the content provided in the survey were biased, with the assumption that technical standards and technical standards education are essential. The survey intended to understand the challenges technical standards users face but may also overestimate the percentage of challenges and the extent to which engineers think technical standards education is important. A few participants stated that they do not use technical standards in their daily engineering jobs, did not see value in such education at the undergraduate level, and did not believe there is a need for additional technical standards education in the engineering curriculum. This number may have been different with a different group of participants or survey questions.

Additional studies should be conducted with larger participant groups, specialized participant groups, and financial compensation to encourage stronger participation and more elaborate feedback. The data presented here should be used as a jumping-off point. The ratios and differences between analytical categories are likely of more value than the frequency counts and percentages themselves due to the inherent bias in the survey. The survey assumed that respondents faced challenges with technical standards, and the multiple-choice section listed options that participants could identify. As a result, the frequency counts may be higher than in a study that did not assume challenges were present and did not contain multiple-choice questions. Additionally, these frequency percentages may be different if surveying only engineers or only the public; however, the data here serves as a good starting point. Few technical standards surveys in the literature include such a large sample size (N=201). It is noteworthy that so many individuals were willing to take a 5–10-minute survey with zero compensation and share it with their colleagues.

Studies looking at technical standards education based on gender due to the historically and well-documented lack of female involvement in technical standards would also be of value and is not present in the literature. The authors did not think to include gender as an identifier until after the survey was well underway.

Additionally, studies that are conducted in person would be beneficial as they would allow for clarification of words and terms used by the respondent that may not have the same significance in the context of technical standards to individuals in different backgrounds, with different levels of experience, or in different engineering disciplines.

Conclusion

This study reinforces a need for technical standards education that accurately represent today's engineers. Ninety-three percent of survey participants reported challenges when engaging with technical standards and technical standards education. Likewise, 89% of participants listed reasons why technical standards education was important. However, engineers, students, and educators face a plethora of challenges. As mentioned in the introduction and alluded to in the coding process, the terminology used to discuss technical standards and their challenges is not standardized, taught, or easily described. This challenge makes researching technical standards education tough. Technical standards challenges and their viewed importance change across the lifetime of an engineer, by putting numbers and names to these challenges and importance categories through coding the engineering community and academic community has access to another tool to make a change.

Acknowledgments

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Appendix A

Additional graphs not included in the paper but consulted during the analysis are included below.

Figure 5: Free response high-order frequency percentage for all survey respondents.

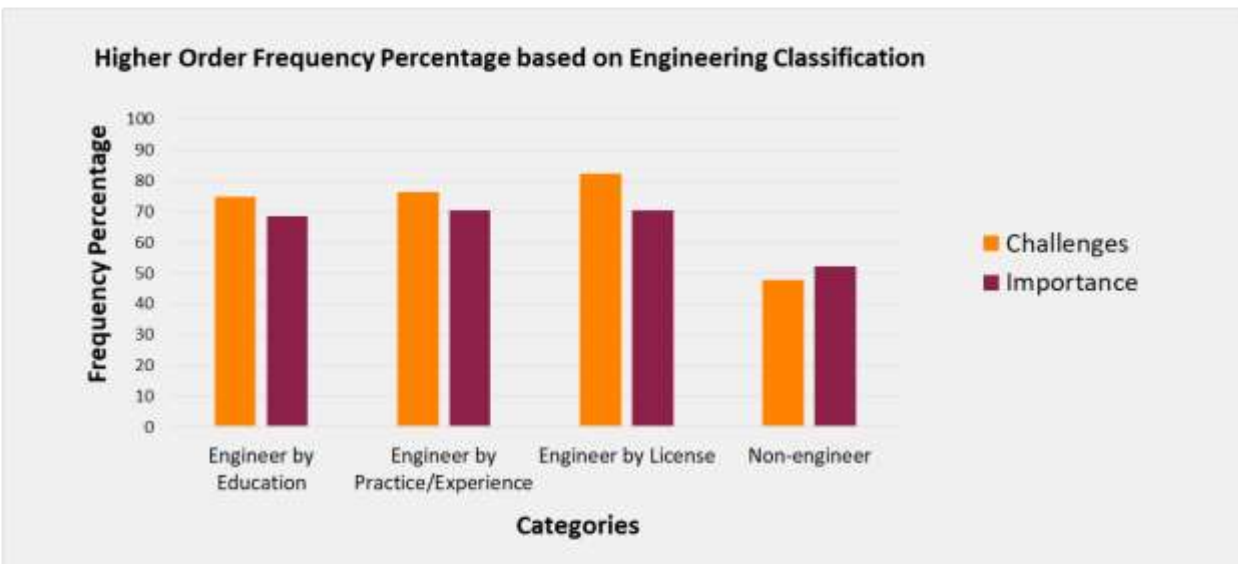

Figure 6: Free response high-order frequency percentage for all survey respondents based on engineering classification.

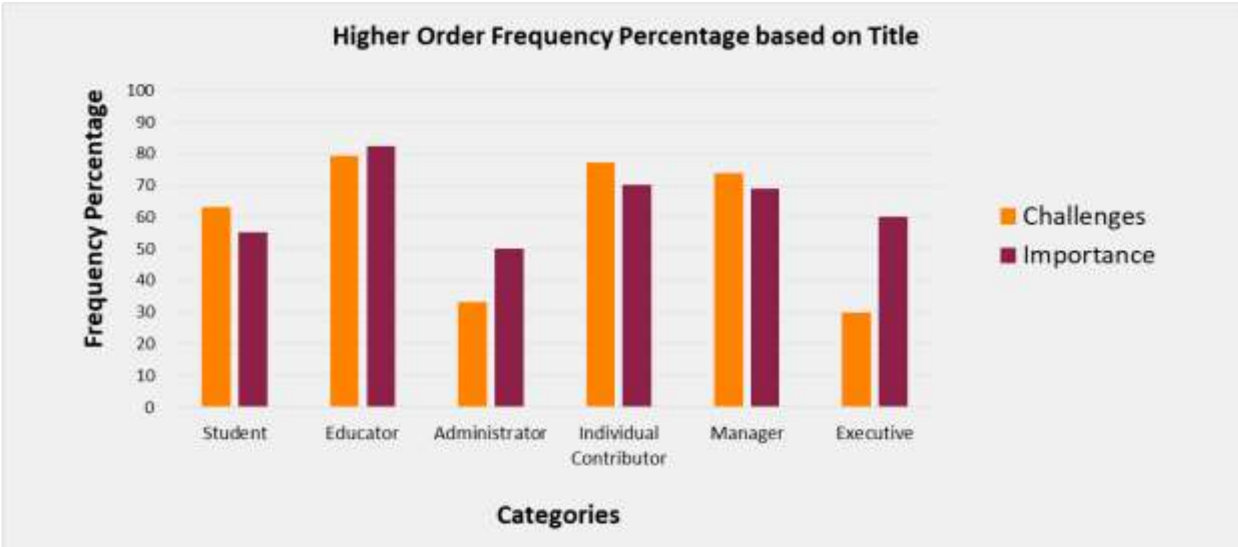

Figure 7: Free response high-order frequency percentage for all survey respondents based on title.

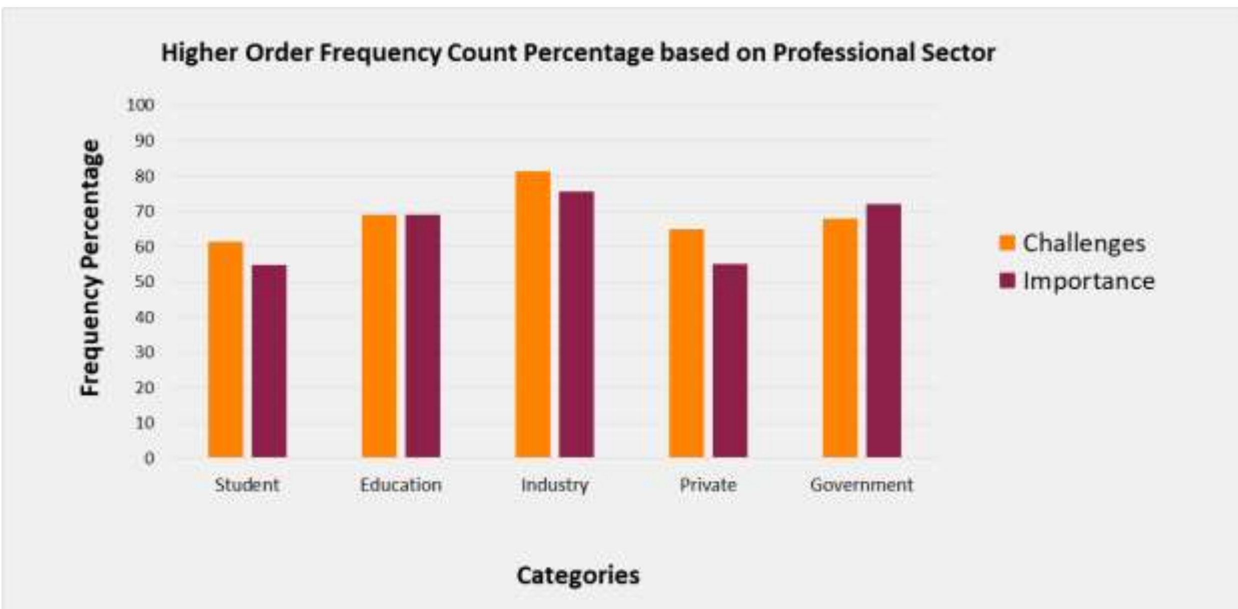

Figure 8: Free response high-order frequency percentage for all survey respondents based on professional sector.

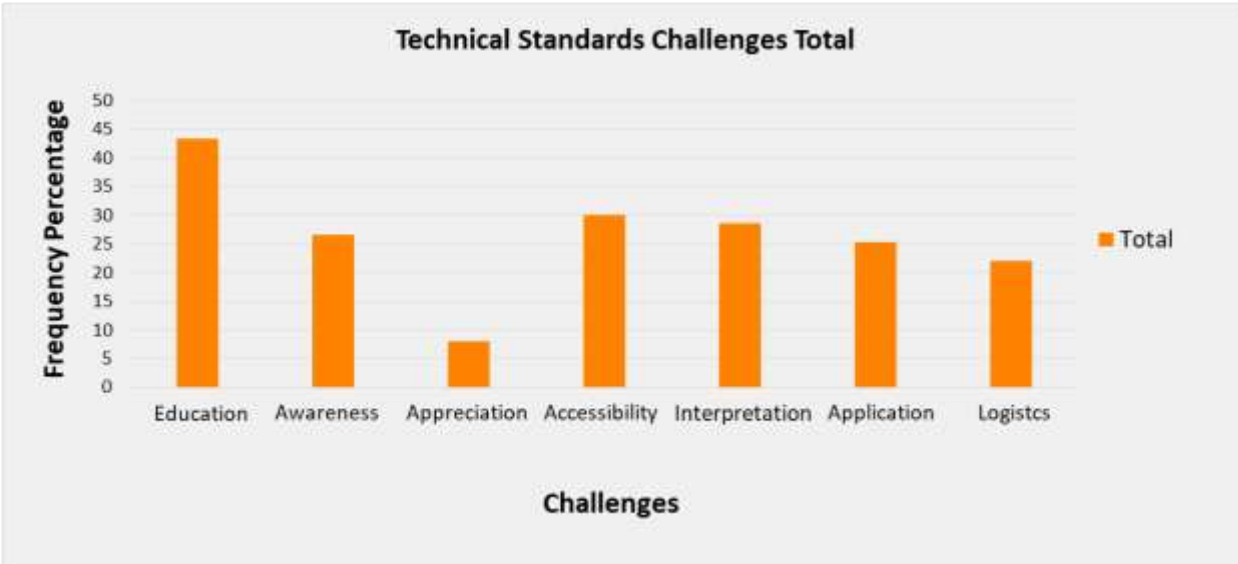

Figure 9: Free response low-order frequency percentage for high-order Challenges based on all survey respondents.

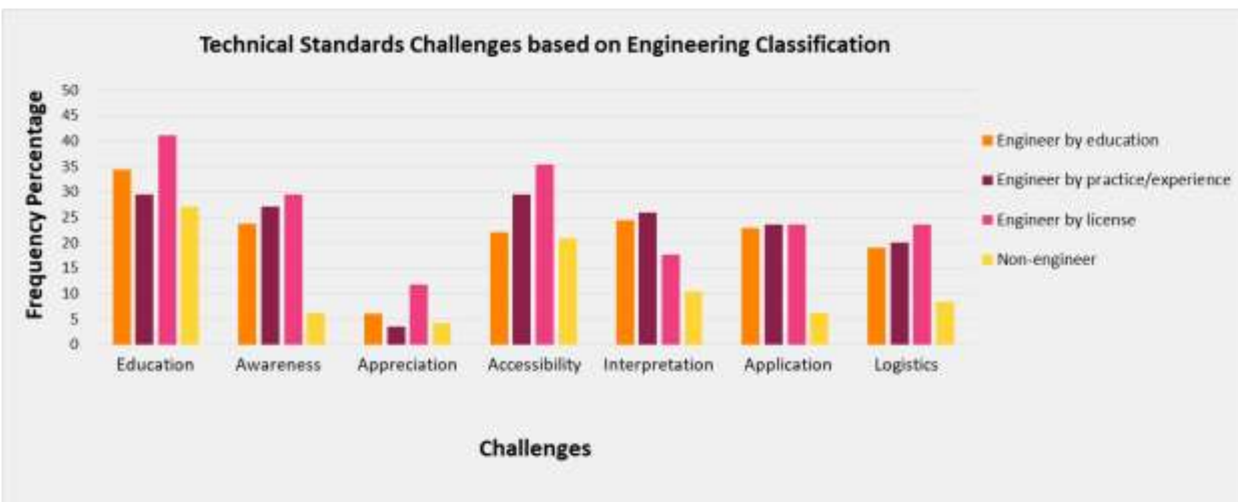

Figure 10: Free response low-order frequency percentage for high-order Challenges based on engineering classification.

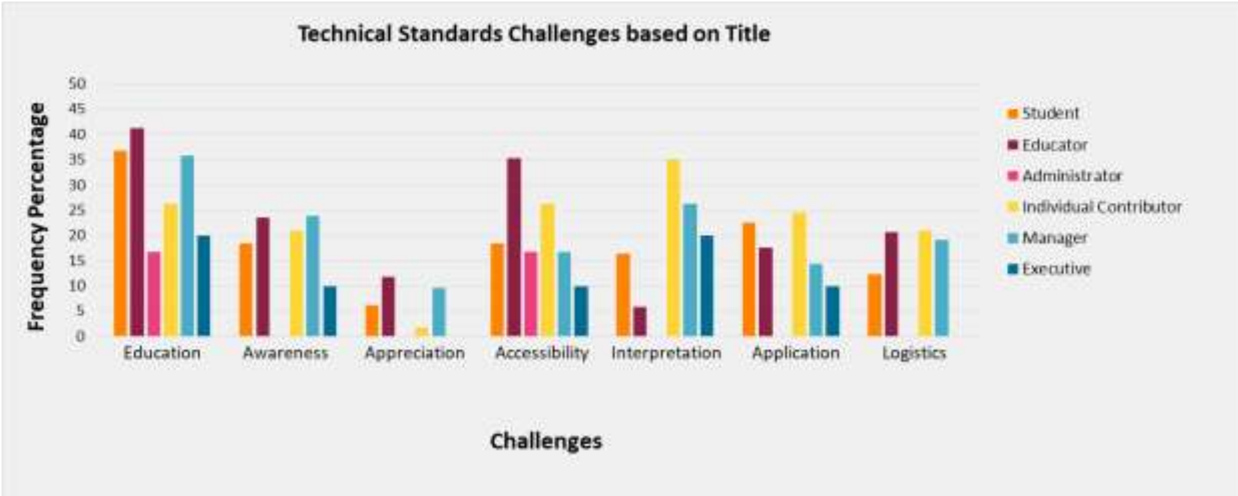

Figure 11: Free response low-order frequency percentage for high-order Challenges based on title.

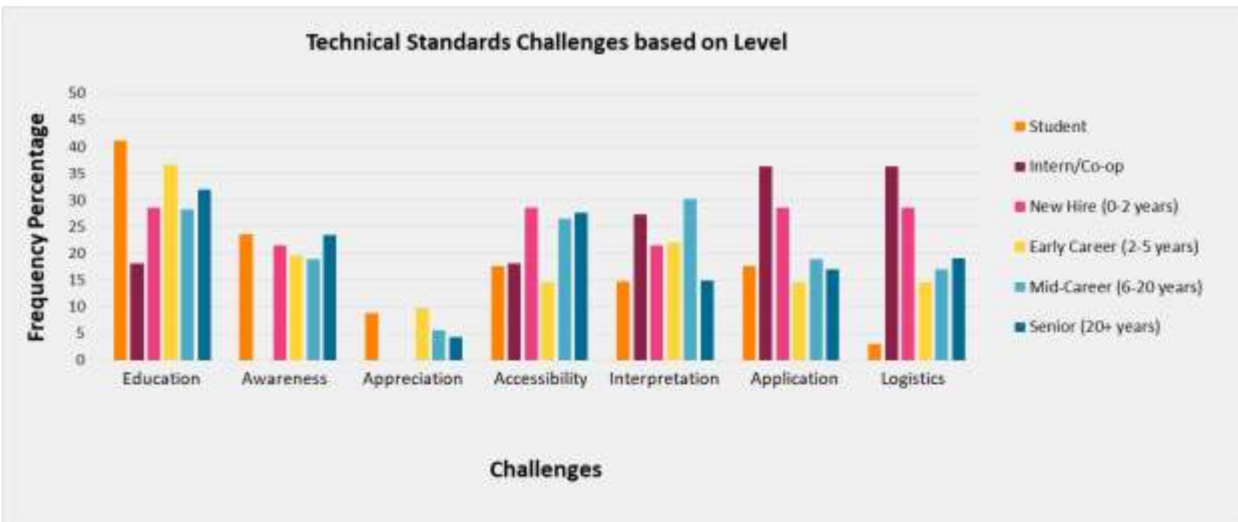

Figure 12: Free response low-order frequency percentage for high-order Challenges based on the professional sector.

Figure 13: Free response low-order frequency percentage for high-order Importance based on all survey respondents.

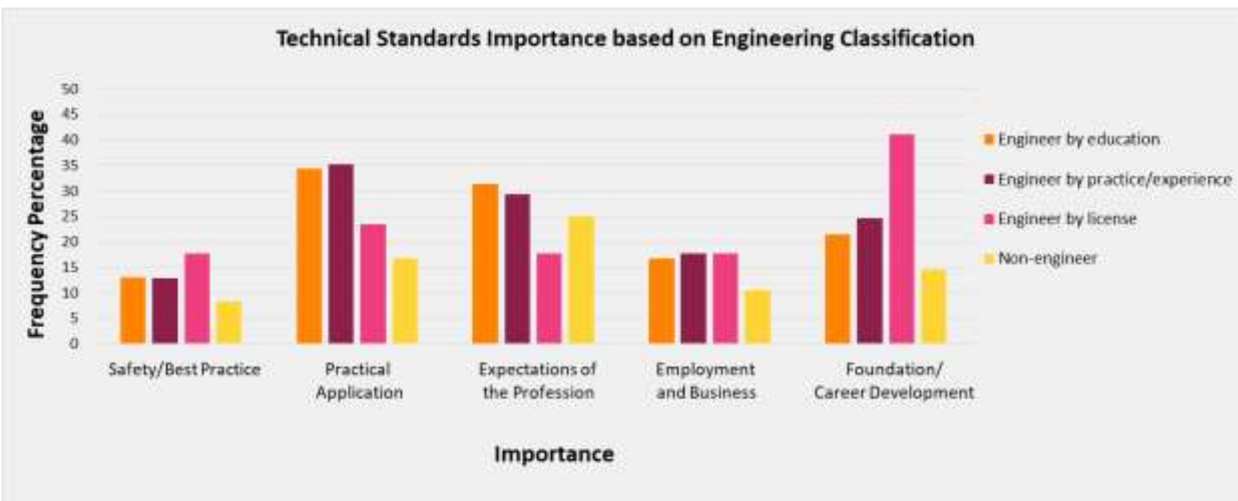

Figure 14: Free response low-order frequency percentage for high-order Importance based on engineering classification.

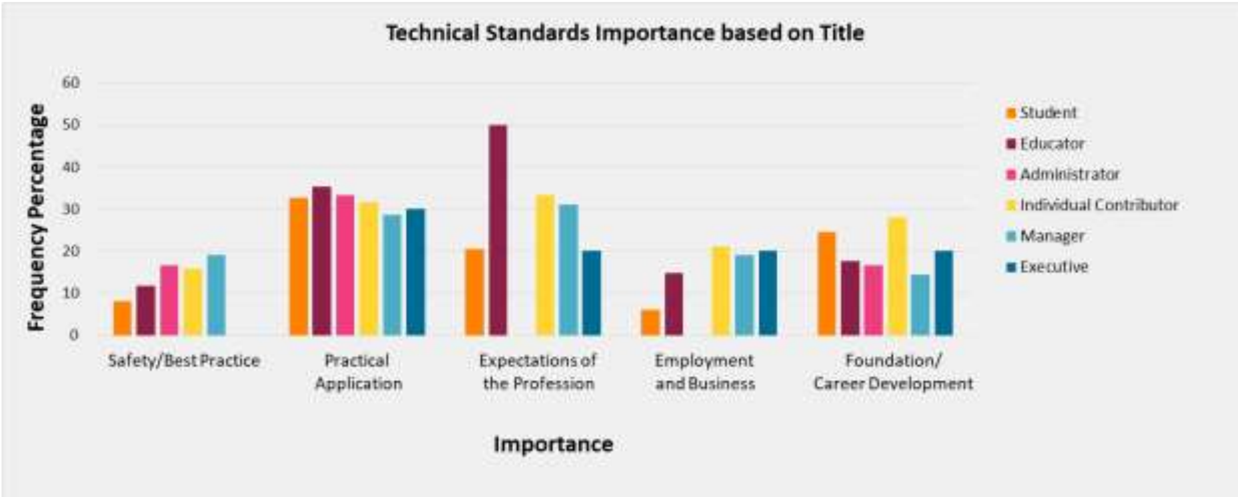

Figure 15: Free response low-order frequency percentage for high-order Importance based on title.

Figure 16: Free response low-order frequency percentage for high-order Importance based on sector.