2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #37464

Changing the Conversation Surrounding Students' Professional Skills: Making the Case for the Importance of Professional Skills, and More Inclusive Language

Dr. Eric Holloway, Purdue University, West Lafayette

Dr. Eric Holloway currently serves as the Sr. Director of Industry Research in the College of Engineering at Purdue, where he focuses on industry research in the College of Engineering. He also holds a courtesy faculty appointment in the School of Engineering Education and Mechanical Engineering.

Dr. Jennifer S. Linvill, Purdue University, West Lafayette

Dr. Jennifer S. Linvill is an Assistant Professor in the Department of Technology Leadership & Innovation at Purdue University. Her research examines organizational communication, particularly in the contexts of destructive workplace behaviors, leadership, teams, and workforce development. Notably, Dr. Linvill is a Co-Principal Investigator on the SCalable Asymmetric Lifestyle Engagement (SCALE) production proposal, funded by the Department of Defense, with colleagues in Purdue's College of Engineering. The project focuses on developing a scalable and sustainable workforce development program for microelectronics that will serve as a model for other workforce development efforts (i.e., artificial intelligence, hypersonics). In this role, she examines organizational and leadership issues that span across an ecosystem of partners within the following areas: defense, government, industry, community colleges, and universities. Dr. Linvill's research is strategically designed to address organizational challenges and create novel solutions to those challenges. Her work has been presented at national and international conferences and has been published in The Routledge Handbook of Communication and Bullying and in Communication, relationships, and practices in virtual work (IGI Global). Dr. Linvill applies an organizational communication lens to her classes on Business Principles, Ethics, Negotiation and Decision Making, Organizational Behavior, and Organizational Leadership, and to Awareness Trainings related to destructive workplace behaviors presented at local high schools. Dr. Linvill is a Member of the Advisory Committee on Equity for the Office of the Vice President for Ethics and Compliance at Purdue University. She has also served as a Mentor for the USAID Liberia Strategic Analysis Program, mentoring an early-career Liberian woman on leadership and communication skills, professional development, and networking.

Changing the conversation surrounding students' professional skills: Making the case for the importance of professional skills, and more inclusive language

Abstract
The engineering education community has integrated non-technical professional skills (e.g., communication, leadership, lifelong learning, teamwork) into the curriculum through direct curricular activities and, more importantly, through co-curricular and extracurricular activities where students get real experiences practicing and honing their non-technical professional skills. However, according to employers, gaps persist in students' perceived professional skills. The purpose of this paper is to assist in changing the conversation about students' professional skills by reviewing the history of how students' professional skills are developed and making a case for the importance of professional skills. This study utilized bibliometric and content analysis tools to search for and identify articles of interest related to how the language of students' professional skills has changed over the past 20 years across a wide range of databases and search terms. The bibliometric and content analysis showed that the predominant term for professional skills in the past 20 years has been "soft skills," which connotes that professional skills are somehow less important than technical skills. The key takeaway from this paper is that the language around students' professional skills needs to change. Additionally, Engineering educators need to focus on encouraging and providing more opportunities outside of the classroom for students to develop their professional skills in real-world contexts that are more realistic for what students will see in their work life. Industry practitioners can help immensely by adopting more inclusive language toward professional skills and providing internship opportunities to incorporate these skills for students to gain real-world experience.

Tags: curriculum, professional skills, real-world experiences, "soft skills," workforce development

1. Introduction

In 2011, at the ASEE annual conference, the Educational Research and Methods Division (ERM) Division ran a conference session titled "They're Not "Soft" Skills!" [1] with the tagline, "There's nothing "soft" about these difficult skills." This session was hardly the first time this case had been made. Since that session in 2011, over ten years ago now, a casual search on the term "soft skills" on the ASEE PEER network brings up approximately 622 publications since 2011, while about the same number of papers focused on "professional skills" (approximately 600). Anecdotally, a 50%/50% uptake on moving away from the term "soft skills" is about what can be seen in daily use by faculty and students, although less from our industry colleagues. However, more progress is needed in changing the dialogue surrounding non-technical professional skills required to be successful in Engineering-related careers.

We are hardly the first to call for change in language around the non-technical professional skills that students develop that are vital to their careers, herein referred to as professional skills. For decades scholarship from multiple disciplines, including communication [2-4], education [5] engineering [6], and engineering education, have called for the development of students with specific professional skills. Parlamis and Monnot [7] make a strong case that "soft skills" is a loaded term – "soft" does not adequately describe the importance of professional skills that business students need in their career development.

Professional skills (e.g., communication, leadership, lifelong learning, teamwork) are ubiquitous in engineering education and today's workforce. Organizations such as ABET and the National Association of Colleges and Employers (NACE) have long stressed the dual importance of both technical and professional skills in today's graduates. The engineering education community has integrated professional skills into the curriculum through direct curricular activities and, more importantly, through co-curricular and extracurricular activities where students obtain real experience practicing and honing their professional skills.

The focus on the development of students who can effectively utilize a set of professional skills is not surprising, given that the global economy is currently situated within a knowledge-based context [8] where professional skills are critical to business success [9]. For example, Moldoveanu and Narayandas [9], note that organizations across a wide variety of industries recognize and value professional skills necessary for survival in today's complex knowledge economy. Professional skills are valued at all levels and are no longer considered to be important solely for those in leadership and C-suite roles [9]. However, organizations continue to find that employees lack the necessary professional skills needed to sustain organizational capabilities and remain competitive [9]. According to recent research, employers indicate that gaps persist in students' perceived professional skills [10]. In short, professional skills are necessary for individuals to be both career- and workforce-ready and for sustaining businesses long term [11, 12]. Yet practitioners [13-15] and scholars [16-19] continue to refer to professional skills as "soft skills," with the implied connotation that professional skills are not as important as technical skills [7, 20].

The purpose of this paper is to assist in changing the conversation about professional skills by reviewing the history of how students' professional skills are developed and making the case for the importance of professional skills. The research questions for the study are: (1) how has the history of the language used to emphasize students' professional skills changed over time, and what language is used today? (2) How can institutions emphasize students' professional skills development to close the perceived gap with technical skills? (3) How can practitioners in industry support students' development of professional skills? Next is a brief review of industry perspectives on the current state of students' professional skills gaps when entering the workforce and current best practices for how engineering educators develop students' professional skills.

2. Background Literature on Students' Professional Skills

Within the field of engineering education, there have been calls to develop students as professionals [20]. For example, the American Society for Engineering Education (ASEE) has engaged in collaborative discussions with key players in industry, government, and academic sectors to develop engineering program standards for accreditation [21]. These standards have since evolved over several decades [11, 20]. Notably, in 1997, ABET adopted new criteria (Criterion 3) that included eleven outcomes that engineering students should have when graduating from ABET-accredited institutions – five technical and six professional skills [11, 20]. Since that time, and in response to Schuman and colleagues' [20] call to develop students as professionals, ABET has updated the professional skills that must be included by accredited engineering programs, which continues to reinforce the importance of developing engineers with professional skills.

The development of students' professional skills is much different from their technical skills. Technical skills generally are more straightforward to teach in a classroom or lab setting, can be taught with repetitive practice, and can often be taught in a sequence of courses [20]. Professional skills are much different; these skills can be introduced and fostered in the classroom, but often take longer to develop than technical skills, and often need to be practiced outside the classroom in real-world situations before they become fully crystalized [20]. For example, the professional skill of leadership is widely studied, and there are many examples of best practices in the classroom [22], but at best, leadership can only be simulated in the classroom, and students must experience it through projects, students organizations, internships, and other activities typically outside the classroom. In fact, research shows that students develop most of their professional skills through participation in co-curricular and extracurricular activities [23-27], such as co-ops, undergraduate research, service learning, student organizations, and the like. Students need these opportunities, outside of the classroom, with real-world experiences to develop context and subsequently fine-tune their professional skills.

3. Theoretical Framework

This study employed professionalism as the theoretical lens. Specifically, Dall'Alba's [5] framework that describes "being/becoming a professional" was used to place Engineering students' development of professional skills needed to be career-ready into conversation with what it means to be professional. Doing so brought student development of both technical and professional skills, through STEM curriculum, co-curricular and extracurricular activities, and internship experiences, into sharper focus as this study examined the perceived gaps in students' development of professional skills.

Institutions of higher education generally follow a method of student development that integrates epistemology and ontology. Curriculum relies on epistemology (i.e., theory of knowing; what is knowledge and how is it acquired?) by imparting technical knowledge and skills needed to "be a professional" in a profession or occupation. Within this type of student development, institutions of higher education generally add an ontological component (i.e., theory of being; what are the fundamental parts and how are they related) as a mechanism for students to acquire ways of "being professional" [5]. For example, engineering students develop knowledge and skills related to their specific discipline of engineering (i.e., epistemology) so that they may recognize ethical issues and engage in ethical decision-making to create engineering solutions (i.e., ontology). However, graduate students often find it difficult to be a professional through their development as students [28]. The difficulty generally occurs in transferring specific knowledge and skills obtained as students to real-world application and with being sufficiently prepared to enter into professional practice [29, 30].

Importantly, three different theoretical frameworks have considered this challenge to student development [30, 31] and were applied to the study's review of student development. First, Säljö's [32] sociocultural framework proposed that students have limited social or cultural understanding of the meaning of being a professional. Hence students find it challenging to move beyond gaining knowledge and skills to then actively situate the knowledge and skills that they develop within real-world contexts, and/or to apply social or cultural meaning in order to become professional. Second, Chi and colleagues [33] applied a separate coherence framework whereby

students incorrectly assume that the epistemological knowledge they have gained directly applies to a professional setting, making becoming professional in a professional setting difficult. Third, Dall'Alba's [5] Ways of Being framework was critical of higher education programs that seek only to prepare students with the knowledge and skills necessary for "being professional" and do not consider an additional process of learners "becoming" professional. Dall'Alba's [5] Ways of Being framework combined the Säljö [32] and Chi [33] frameworks into a more specific and robust framework that integrated epistemological (knowing) and ontological (being) into a process where students can both "be" and "become" a professional. The Ways of Being framework posits that to "be professional," one must engage in the process of "becoming a professional" through purposeful "integration of knowing, acting, and being" that occurs over time [5].

4. Methods

In order to understand how the terms "soft skills" and "professional skills" have proliferated over time in the literature and across various disciplines, countries, funding sponsors, etc., a bibliometric search was conducted utilizing the Scopus database. Scopus was utilized for several reasons, including the database access to several indexed journal databases, its analysis tools, and its search capabilities.

Two main searches were targeted for comparison across all disciplines: the first was on the term "soft skills" for the years 1980–2022, which returned 1042 documents. The second was on the term "professional skills" for the same years 1980–2022, which returned 692 documents. 1980 was chosen as the initial year so as to predate the timeframe before the term "soft skills" became popular.

Four main analyses were completed based on the results that were returned from Scopus: (1) publication trends by year; (2) publication trend by year by discipline, with a particular focus on engineering; (3) publications by subject areas; (4) publications by country; (5) publications by funding sponsor.

5. Results

The results sections below show publication trend charts for the five areas described in the methods sections. Some of the trend charts (publications trends by year, country, and funding sponsor) are screenshots directly from Scopus, while the other trends chart (publication trends by year by discipline and by subject area were generated in Excel from the Scopus data.

5.1 Publication Trends by Year

Figure 1 below shows the trend for "Soft Skills" publications from 1980-2022 for all disciplines, with a total of 1042 publications. Figure 2 below shows the same timeline for "Professional Skill" publications, with a total of 692 publications in the same timeframe. Note the large increase in both "soft skills" and "professional skills" after approximately 2015, but more so in the area of "soft skills."

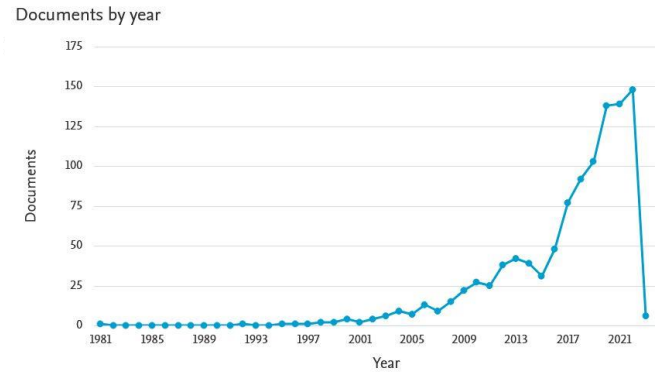

Figure 1: "Soft Skills" Publications: 1980-2022, All Disciplines, Total 1042.

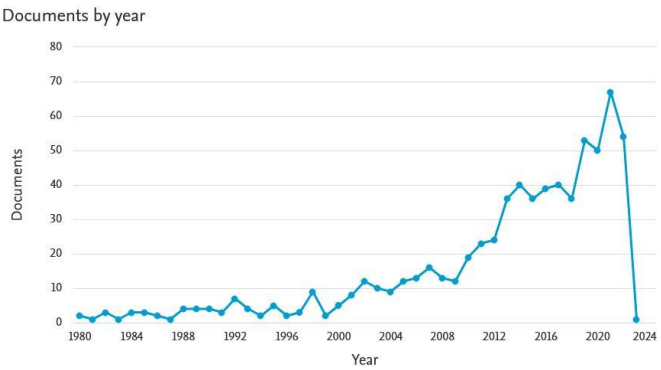

Figure 2: "Professional Skills" Publications: 1980-2022, All Disciplines, Total 692.

5.2 Publication Trends by Year by Discipline (For All vs. Engineering)

Figure 3 below shows the trend for "Soft Skills" vs. "Professional Skills" publications from 1980-2022 for all disciplines, with a total of 1042 publications for "Soft Skills and 692 for "Professional Skills."

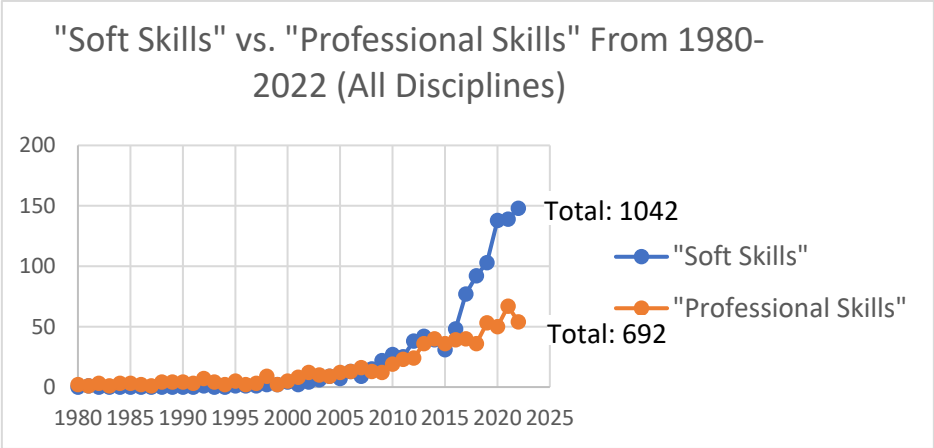

Figure 3: "Soft Skills" vs. "Professional Skills" Publications: 1980-2022, All Disciplines.

Figure 4 below shows the trend for "Soft Skills" vs. "Professional Skills" publications from 1980-2022 for Engineering, with a total of 257 publications for "Soft Skills and 242 for "Professional Skills."

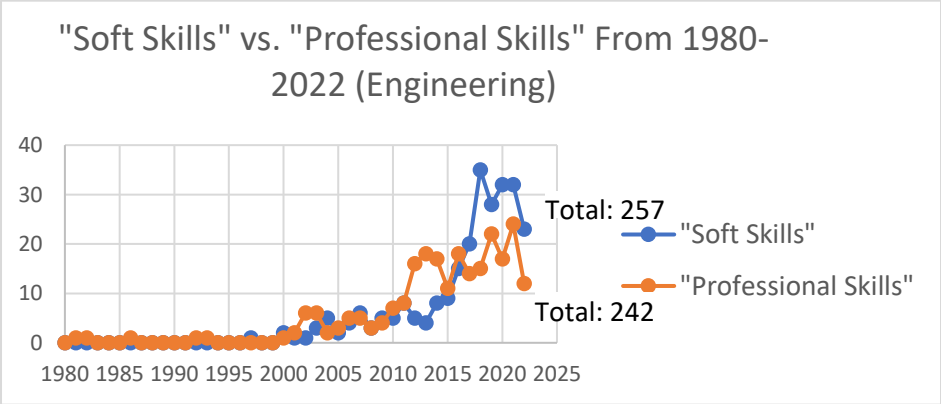

Figure 4: "Soft Skills" vs. "Professional Skills" Publications: 1980-2022, Engineering.

5.3 Publications by Subject Area

Figure 5 below shows the overall percentages for "Soft Skills" publications from 1980-2022 for all disciplines. Note that Engineering is 14.2% of the publication total.

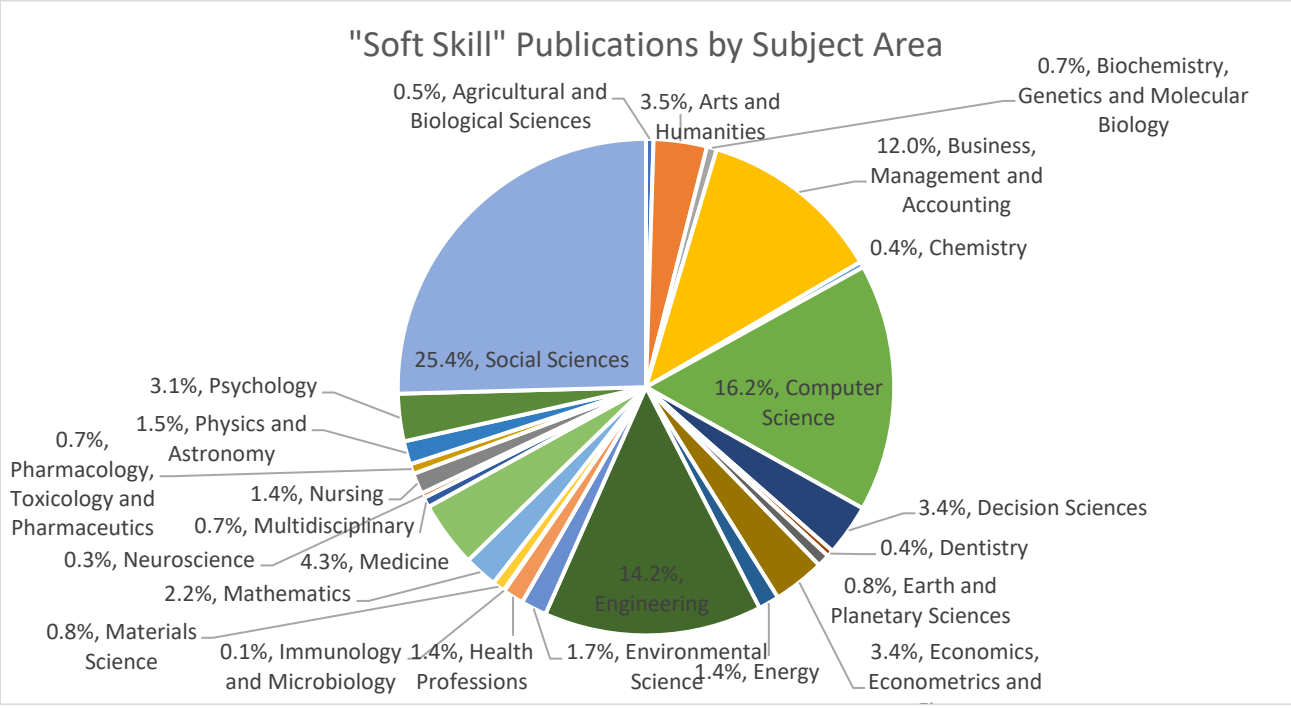

Figure 5: "Soft Skills" Publications: 1980-2022, By Subject Area.

Figure 5 below shows the overall percentages for "Professional Skills" publications from 1980-2022 for all disciplines. Note that Engineering is 21.2% of the publication total.

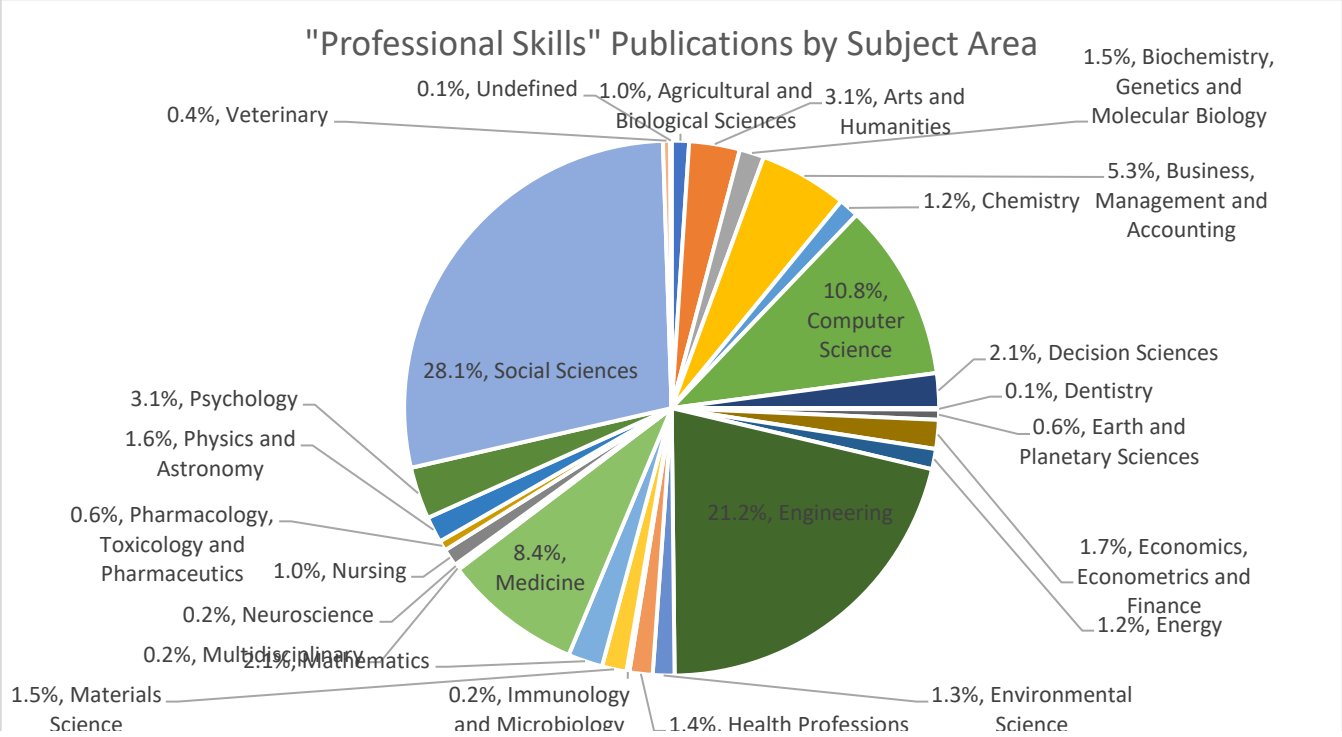

Figure 6: "Professional Skills" Publications: 1980-2022, By Subject Area.

5.4 Publications by Country

Figure 7 below shows “Soft Skills” publications from 1980-2022 for all disciplines by country. Figure 8 below shows “Professional Skill” publications from 1980-2022 for all disciplines by country. Note that the U.S. leads by far in both “soft skills" and "professional skills.”

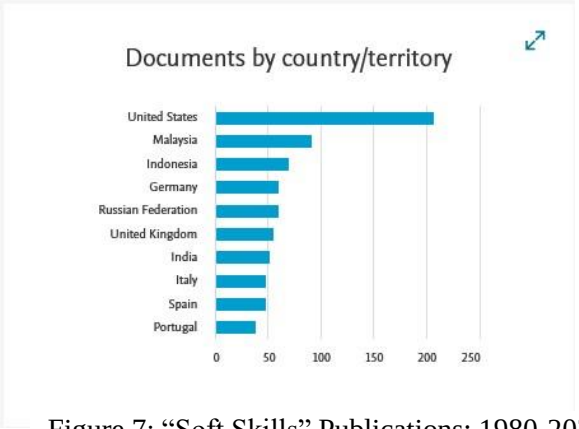

Figure 7: “Soft Skills” Publications: 1980-2022, All Disciplines, By Country.

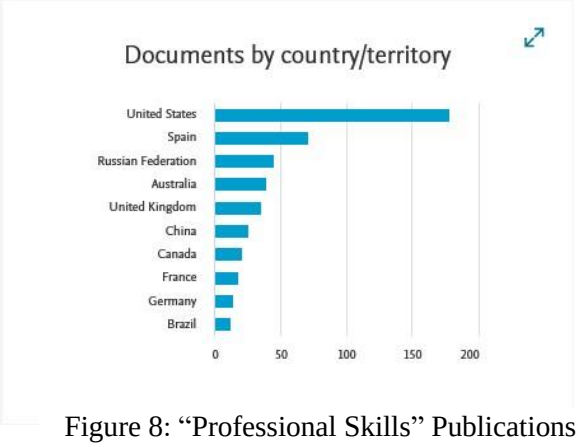

Figure 8: “Professional Skills” Publications: 1980-2022, All Disciplines, By Country.

5.5 Publications by Funding Sponsor

Figure 9 below shows “Soft Skills” publications from 1980-2022 for all disciplines by funding sponsor. Figure 10 below shows “Professional Skill” publications from 1980-2022 for all disciplines by funding sponsor. Note that the leading sponsor for “soft skills” is the European Commission, while the leading sponsor for "professional skills” is NSF.

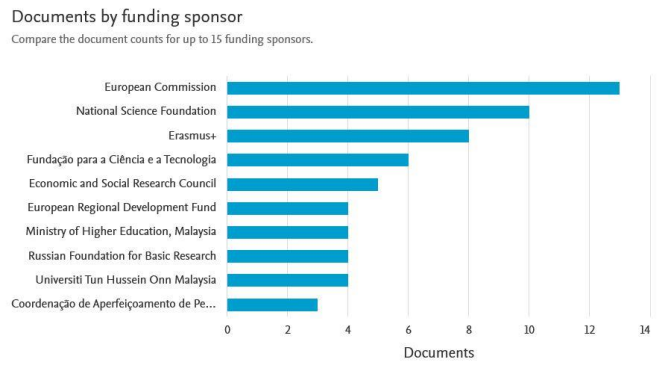

Figure 7: “Soft Skills” Publications: 1980-2022, All Disciplines, By Funding Sponsor.

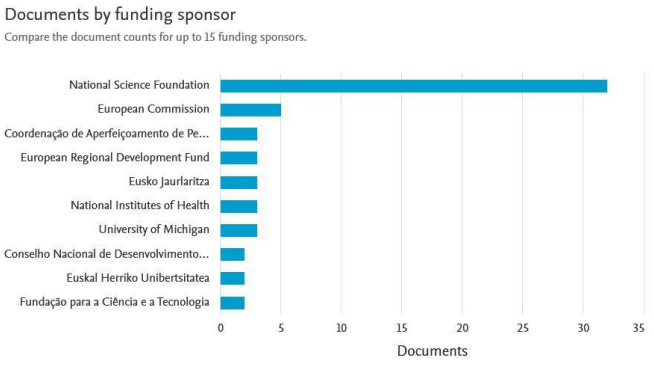

Figure 8: “Professional Skills” Publications: 1980-2022, All Disciplines, By Funding Sponsor.

6. Discussion

The bibliometric analysis and results show several interesting trends. First, the term “soft skills” is still the predominant term used to indicate professional skills in the past 20 years, with an appreciable increase in the usage of the term “soft skills” after approximately 2015. Second, the analysis and results also show that the engineering discipline is helping to lead the way to change the language, as the trend in engineering to move to “professional skills” is faster than the overall rate of other academic disciplines, and engineering is a major contributor to the “professional skills” literature. Third, the U.S., and the National Science Foundation, in particular, have been

key drivers in helping to change the language from “soft skills” to “professional skills.” Despite these positive trends, it is disappointing that the overall trends were not what the researchers hoped to uncover when designing the study. In light of these trends, we recommend some best practices for how institutions of higher education and industry practitioners can move to change the discourse surrounding students’ professional skills.

The term “soft skills” leads to the perception that professional skills are not as important as technical skills, and hence, professional skills may receive less intentional focus from educators and students. Institutions of higher education can take several important steps to change the conversation surrounding professional skills. First, this study encourages engineering education educators to seek to disrupt any lingering traditional view of engineering that keeps professional skills as a separate and often unspoken part of student development. Second, professional skills should be purposefully scaffolded into educational curriculum and explicitly defined, learned, assessed [34, 35], and practiced as part of student preparation. Doing so would allow students to learn about and understand their own professional strengths and weaknesses, and seek to further develop any inadequate areas via co-curricular and extra-curricular mechanisms before the end of their formal education journey. Third, having an awareness of the ways that experts in the workforce expect students to become professionals can help improve student development, the associated student outcomes, and career readiness. By acknowledging the importance of a connection between professional and technical skills, as identified by industry experts, it is more difficult to prioritize the inclusion of one over the other in the engineering curriculum. Fourth, engineering education professionals involved with student development need to focus on encouraging and providing more opportunities outside of the classroom for students to develop their professional skills in real-world contexts that are more realistic for what students will encounter in the workplace.

This study also offers best practices for how industry practitioners can help change the discourse surrounding professional skills. First, industry partners can help immensely by adopting more inclusive language toward professional skills and providing internship opportunities to incorporate these skills for students to gain real-world experience. Second, students’ opportunities for authentic experiences and pursuit of those to develop professional skills are lacking and need to be made up to close the perceived gap with technical skills. Industry best practices will focus on well-rounded internship experiences that provide student interns with opportunities to lead, work in teams, and communicate orally and verbally. Third, providing internships with the previously listed opportunities should include formal mentoring related to both technical and professional skills. Student internships should provide more opportunities to learn and develop student skills, rather than simply providing a warm body to fill a seat. Fourth, industry partners are encouraged to collaborate more closely with higher education to drive the necessary change that is more inclusive of professional skills and in designing internship opportunities that focus on developing career-ready students. One way for industry partners and higher education to partner more successfully for student development would be to utilize the ABET and NACE career-ready competencies as a guide. Using these tools as a starting point, practitioners can more easily identify gaps in the offered internship experiences and make changes to internships accordingly.

7. Conclusions, Limitations, and Implications

The key takeaway from this paper is that the language around students' professional skills needs to change. "Soft skills" is a term that connotates a downgrade in the importance of professional skills, though employers now hire considering professional skills just as much as they do technical skills. Engineering educators have integrated the curriculum with professional skills. Still, they now need to focus on encouraging and providing more opportunities outside of the classroom for students to develop their professional skills in real-world situations that are more realistic for what students will see in the workplace. Industry practitioners can help immensely by adopting more inclusive language toward professional skills and providing internship opportunities to incorporate these skills for students to obtain this real-world experience.

The ultimate goal for seeking to change the conversation surrounding professional skills is for students to become well-developed and career-ready in both professional and technical skills for entry into the engineering workforce. Students who do not develop robust professional skills cannot be fully ready and able to meet the needs of the rapidly changing engineering workforce, despite their technical knowledge. Given this, there are several implications that relate to the best practices for developing career-ready students that are highlighted in this study. Doing so benefits students, industry partners, and the individuals and communities that they eventually serve. Fully-developed students entering the workforce can also serve to bolster the economy. Given this, a focus on professional skill development in students involves thoughtful partnerships among higher education, students, and industry partners to change the conversation to include professional skills.

This study has several limitations for consideration. First, a detailed content analysis may uncover additional context surrounding the types of papers that have examined professional skills and those that utilize the term "soft skills" to describe professional skills. Second, Scopus was utilized for its robust ability to conduct a bibliometric search, including access to several indexed journal databases, its analysis tools, and its search capabilities. Even so, using Scopus only represents one touchpoint of the data that may potentially be available to inform future studies. Third, qualitative interviews might also uncover subtle nuances that this search could not fully identify through a database search. Hearing from individuals who serve as experts in engineering education and from industry partners who are well-versed in both hiring and supervising individuals in internships and in professional engineering positions might serve to further illuminate the progress that has been made and further work that can highlight additional best practices for developing students' professional skills. These are all areas where future work might be useful.

References

[1] American Society for Engineering Education. "T222A - They're Not "Soft" Skills!" https://monolith.asee.org/public/conferences/1/registration/view_session?session_id=174 (accessed 1/22/23).

[2] G. Cheney and K. Lee Ashcraft, "Considering "the professional" in communication studies: Implications for theory and research within and beyond the boundaries of organizational communication," *Communication theory*, vol. 17, no. 2, pp. 146-175, 2007.

[3] P. Motley and A. Sturgill, "Assessing the merits of international service-learning in developing professionalism in mass communication," *Communication Teacher*, vol. 27, no. 3, pp. 172-189, 2013.
[4] C. Simonsson and M. Heide, "Developing a Communicative Logic –The Key to Communication Professionalism," *International Journal of Strategic Communication*, vol. 15, no. 3, pp. 253-273, 2021/05/27 2021, doi: 10.1080/1553118X.2021.1906682.
[5] G. Dall'Alba, "Learning professional ways of being: Ambiguities of becoming," *Educational Philosophy and Theory*, vol. 41, no. 1, pp. 34-45, 2009, doi: 10.1111/j.1469-5812.2008.00475.x.
[6] J. Wang, Y. C. Fong, and W. Alwis, "Developing professionalism in engineering students using problem based learning," in *Proceedings of the 2005 Regional Conference on Engineering Education*, 2005, pp. 1-9.
[7] J. Parlamis and M. J. Monnot, "Getting to the CORE: Putting an end to the term "soft skills"," *Journal of Management Inquiry*, vol. 28, no. 2, pp. 225-227, 2019, doi: 10.1177/1056492618818023.
[8] P. Drucker, *Managing for the future*. Oxford: Butterworth-Heinemann, 1992.
[9] M. Moldoveanu and D. Narayandas. "The future of leadership development." Harvard Business Review. https://hbr.org/2019/03/the-future-of-leadership-development (accessed Jan 1, 2022).
[10] J. S. Linvill, I. N. Adams, E. M. Haluschak, B. S. Quezada, and T. J. Moore, "Good communication skills are super super important': Developing students' professional communication skills for career ready engineers," presented at the American Society for Engineering Education Annual Conference, Baltimore, MD, 2023.
[11] ABET. "Criteria for Accrediting Engineering Programs, 2022 – 2023." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/ (accessed 1/1/2022).
[12] National Association of Colleges and Employers. "Career readiness defined." https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/ (accessed 1/1/2022).
[13] T. Chamorro and B. Frankiewicz. "Does higher education still prepare people for jobs?" Harvard Business Review. https://hbr.org/2019/01/does-higher-education-still-prepare-people-for-jobs (accessed Jan 1, 2022).
[14] S. M. Kosslyn. "Are you developing skills that won't be automated?" Harvard Business Review. https://hbr.org/2019/09/are-you-developing-skills-that-wont-be-automated (accessed Jan 1, 2022).
[15] J. Meister. "How companies are using VR to develop employees' soft skills." Harvard Business Review. https://hbr.org/2021/01/how-companies-are-usingvr-to-develop-employees-soft-skills (accessed Jan 1, 2022).
[16] J. Dixon, C. Belnap, C. Albrecht, and K. Lee, "The importance of soft skills," *Corporate finance review*, vol. 14, no. 6, p. 35, 2010.
[17] M. L. Matteson, L. Anderson, and C. Boyden, "Soft skills": A phrase in search of meaning," *portal: Libraries and the Academy*, vol. 16, no. 1, pp. 71-88, 2016.
[18] B. Schulz, "The importance of soft skills: Education beyond academic knowledge," 2008.
[19] M. Wats and R. K. Wats, "Developing soft skills in students," *International Journal of Learning*, vol. 15, no. 12, 2009.

[20] L. J. Shuman, M. Besterfield-Sacre, and J. McGourty, "The ABET "professional skills"—Can they be taught? Can they be assessed?," *Journal of Engineering Education*, vol. 94, no. 1, pp. 41-55, 2005, doi: https://doi.org/10.1002/j.2168-9830.2005.tb00828.x.
[21] A. Akera, "Setting the standards for engineering education: A history [scanning our past]," *Proceedings of the IEEE*, vol. 105, no. 9, pp. 1834-1843, 2017.
[22] R. Paul and L. G. C. Falls, "Engineering leadership education: A review of best practices," in *2015 ASEE Annual Conference & Exposition*, 2015, pp. 26.634. 1-26.634. 11.
[23] S. D. Garrett, J. P. Martin, and S. G. Adams, "Developing nontechnical professional skills in African American engineering majors through co-curricular activities," *IEEE Transactions on Education*, vol. 65, no. 3, pp. 394-401, 2021.
[24] D. F. Carter, H. K. Ro, B. Alcott, and L. R. Lattuca, "Co-curricular connections: The role of undergraduate research experiences in promoting engineering students' communication, teamwork, and leadership skills," *Research in Higher Education*, vol. 57, pp. 363-393, 2016.
[25] D. Jackson and R. Bridgstock, "What actually works to enhance graduate employability? The relative value of curricular, co-curricular, and extra-curricular learning and paid work," *Higher Education*, vol. 81, no. 4, pp. 723-739, 2021.
[26] C. J. Finelli *et al.*, "An assessment of engineering students' curricular and co-curricular experiences and their ethical development," *Journal of Engineering Education*, vol. 101, no. 3, pp. 469-494, 2012, doi: https://doi.org/10.1002/j.2168-9830.2012.tb00058.x.
[27] J. L. Huff, C. B. Zoltowski, and W. C. Oakes, "Preparing engineers for the workplace through service learning: Perceptions of EPICS alumni," *Journal of Engineering Education*, vol. 105, no. 1, pp. 43-69, 2016, doi: 10.1002/jee.20107.
[28] E. Holloway and D. Radcliffe, "Review of global trends in knowledge, skills, and abilities (KSA) frameworks applicable to Ph.D. programs in engineering," presented at the American Society for Engineering Education Annual Conference, Salt Lake City, UT, 2018. [Online]. Available: https://doi.org/10.18260/1-2--30938.
[29] E. National Academies of Sciences, and Medicine,, *Graduate STEM education for the 21st century*. Washington, DC: The National Academies Press (in English), 2018, p. 174.
[30] E. A. Holloway, K. A. Douglas, D. F. Radcliffe, and W. C. Oakes, "Research experiences instrument: Validation evidence for an instrument to assess the research experiences of engineering PhD students' professional practice opportunities," *Journal of Engineering Education*, vol. 111, no. 2, pp. 420-445, 2022, doi: https://doi.org/10.1002/jee.20451.
[31] E. Holloway, D. F. Radcliffe, K. A. Douglas, and W. C. Oakes, "Assessing engineering Ph.D. students' research experiences: What is important to assess?," presented at the Paper presented at the American Society for Engineering Education Annual Conference & Exposition, Virtual on line, 2020. [Online]. Available: https://doi.org/10.18260/1-2--34175.
[32] R. Säljö, "Concepts, cognition and discourse: From mental structures to discursive tools," in *New perspectives on conceptual change. Advances in learning and instruction series*, W. Schnotz, S. Vosniadou, and M. Carretaro Eds. Amsterdam: Pergamon, 1999, pp. 81-90.
[33] M. T. Chi, R. D. Roscoe, J. D. Slotta, M. Roy, and C. C. Chase, "Misconceived causal explanations for emergent processes," *Cognitive Science*, vol. 36, no. 1, pp. 1-61, 2012, doi: 10.1111/j.1551-6709.2011.01207.x.

[34] T. Li , E. A. Holloway, V. Bill, K. A. Douglas, and J. P. Martin, "Professional skill opportunities survey: Development and exploratory factor analysis.," presented at the Paper presented at the Frontiers in Education Annual Conference, Uppsala, Sweden, 2022. [Online]. Available: https://doi.org/10.1109/FIE56618.2022.9962700.

[35] T. Li, E. A. Holloway, V. G. Bill, K. A. Douglas, and J. P. Martin, "Professional skill opportunities survey: Development and exploratory factor analysis," pp. 1-8, 2022, doi: 10.1109/FIE56618.2022.9962700.