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Gauging Diversity and Inclusion in Systems Engineering Education

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Abstract

Many institutions are transitioning to more diverse and inclusive operating policies. Specifically, the policies encourage more diverse and inclusive populations as a means to better decipher and resolve complex issues. The field of engineering is no exception, with considerable effort directed toward expanding underrepresented student enrollment in engineering programs. This study explores the current trends of diversity and inclusion in engineering education publishing and degree attainment. The resultant metrics may inform and improve measures to achieve a more heterogeneous engineering workforce.

Keywords: Diversity, Inclusion, Engineering Education, Systems Engineering

1. Introduction

Many institutions of higher learning are working towards increasing student diversity and inclusion in engineering programs. This study explores the current research trends and demographic makeup of university engineering programs. The goal of this study is to gain insight into these trends and better understand the challenges to diversity and inclusion efforts within systems engineering education. This study can provide a foundation to advance diversity and inclusion in systems engineering education toward a more heterogeneous engineering workforce.

2. Literature Review

The literature contains various definitions for diversity and inclusion [1]. Because this study focuses on diversity and inclusion within systems engineering education, the study will focus on diversity and inclusion definitions of the International Council on System Engineering (INCOSE). INCOSE's policy DEI-100 defines diversity as "the range of human differences, encompassing the characteristics that make one" [2]. INCOSE defines inclusion as "the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others" [2]. The foundation of INCOSE's definitions is the Accreditation Board for Engineering and Technology (ABET) definitions for diversity and inclusion.

ABET defines diversity as "the range of human differences, encompassing the characteristics that make one individual or group different from another. Diversity includes, but is not limited to, the following characteristics: race, ethnicity, culture, gender identity and expression, age, national origin, religious beliefs, work sector, physical ability, sexual orientation, socioeconomic status, education, marital status, language, physical appearance, and cognitive differences" [3]. ABET defines inclusion as "the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others. An inclusive environment provides equitable access

to opportunities and resources, empowers everyone to participate equally, and offers respect in words and actions for all" [3]. This study will utilize these definitions to assist in establishing the context for diversity and inclusion in systems engineering education.

3. Methodology

The study will utilize a bibliometric analysis to determine the current temporal and spatial tendencies of diversity and inclusion within systems engineering education publishing. Bibliometric analysis is an established and assiduous technique for scrutinizing vast quantities of technical data to realize emerging patterns for a particular topic. A bibliometric analysis may uncover emerging article trends, publication performance, collaboration patterns, research elements, and explore the intellectual structure of a specific realm within the existing literature [4]. This study hypothesizes that both diversity and inclusion research within systems engineering education is increasing. The bibliometric approach consists of querying academic databases and Google Books Ngram to collect indexed systems engineering education, diversity, and inclusion research. The authors will analyze the results to reveal temporal and spatial patterns to expose the complexity and span of published systems engineering education diversity and inclusion research. These patterns will signify the relevance and reveal potential directions for future research in this field.

4. Analysis & Results

For this article, the authors initially searched databases using the search string "engineering education" AND "systems engineering" AND (diversity OR inclusion) in the indexed and author identified keyword fields of multiple academic databases. This returned only a handful of results. The authors pivoted and searched databases using the search string "engineering education" AND (diversity OR inclusion). Our institution provides access to EBSCO's Discovery platform, UDiscover, and Web of Science. The initial query in the UDiscover database returned 409 results. Unfortunately, the export functionality misfired on multiple occasions, resulting in the export of only 282 results. Furthermore, UDiscover does not provide substantive analysis tools. Searching Web of Science returned only 194 results when using the search string.

At this point, the research team visited a neighboring institution to search Engineering Village and Scopus. The Scopus database returned 651 results and Engineering Village returned 830 results published from 1982 to 2021. Both Scopus and Engineering Village databases provide tools that are useful for bibliometric analysis. This paper focuses on the 830 results from Engineering Village because the search results included more unique search results than any other platform reviewed. The work of combining and deduplicating the results across multiple databases is for a future project.

The Engineering Village results included 572 records from Compendex and 258 records from Inspec. Of these, 645 articles are conference proceedings, and 185 are from peer-reviewed journal articles. Most of the articles are in English (99.5%) with three in Portuguese and two in Spanish.

Figure 1 illustrates the top eleven academic institutions publishing research returned by searches for "engineering education" AND (diversity OR inclusion). Purdue University publishes more articles than any other institution in the United States in this domain, followed by Virginia Tech. Notably, Purdue and Virginia Tech has engineering education programs.

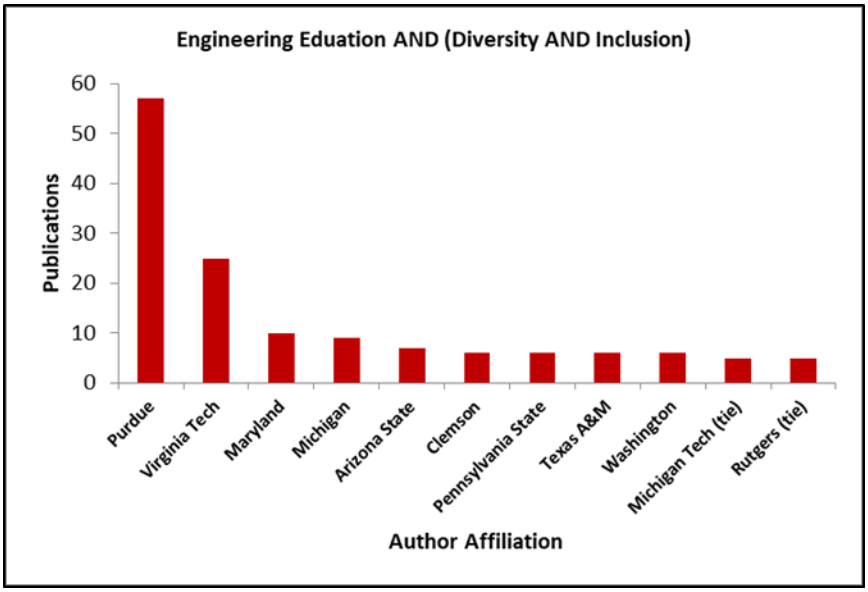


Figure 1: Top Ten (Eleven) United States Author Affiliations for "Engineering Education" AND (Diversity OR Inclusion)

Table 1 illustrates the top five conferences for publication. The Institute of Electrical and Electronic Engineers (IEEE), and the American Society of Engineering Education (ASEE) conferences are the dominant contributors. It is noteworthy that the top five contain a Non-United States entity–the European Society for Engineering Education (SEFI).

Table 1: Top Five Conferences for "Engineering Education" AND (Diversity OR Inclusion)

Conference	Publications
Frontiers in Education Conference	152
ASEE Annual Conference	87
IEEE Global Engineering Conference	39
Annual Conference on Innovation and Technology in Computer Science	15
European Society for Engineering Education (SEFI)	19

Table 2 illustrates the top five journals for publications related to "engineering education" AND (diversity OR inclusion). Like the conference proceedings, the American Society of Engineering

Education (ASEE) and The European Society for Engineering Education (SEFI) are present in the top five.

Table 2: Top Five Journals for "Engineering Education" AND (Diversity OR Inclusion)

Journal	Publications
European Journal of Engineering Education	25
Lecture Notes in Computer Science	15
Journal of Engineering Education	13
Advances of Intelligent Systems and Computing	11
Journal of Professional Issues in Engineering Education and Practice	11

Finally, the authors explored the temporal and spatial aspects of diversity and inclusion within systems engineering education publishing. As previously mentioned, the inclusion of the phrase "System Engineering" produces too few results to identify patterns. Therefore, the database query focused on diversity and inclusion within engineering education.

Figure 3 explores the temporal aspects of the combined terms "engineering education" AND (diversity OR inclusion), illustrating an exponentially upward trend until 2020. COVID-19 disrupted academic teaching and publishing, explaining the observed loss pattern. As universities reboot pre-pandemic operational policies, the true nature of publishing on this topic will materialize.

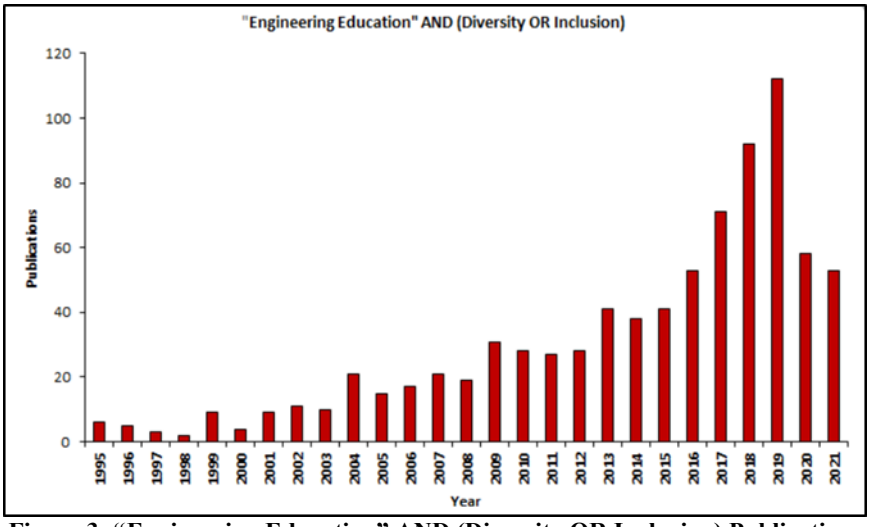


Figure 3: "Engineering Education" AND (Diversity OR Inclusion) Publications

Figure 4 explores the spatial aspect of the combined terms “Engineering Education” AND (Diversity OR Inclusion), clearly illustrating that the United States is the leading country for research in this domain.

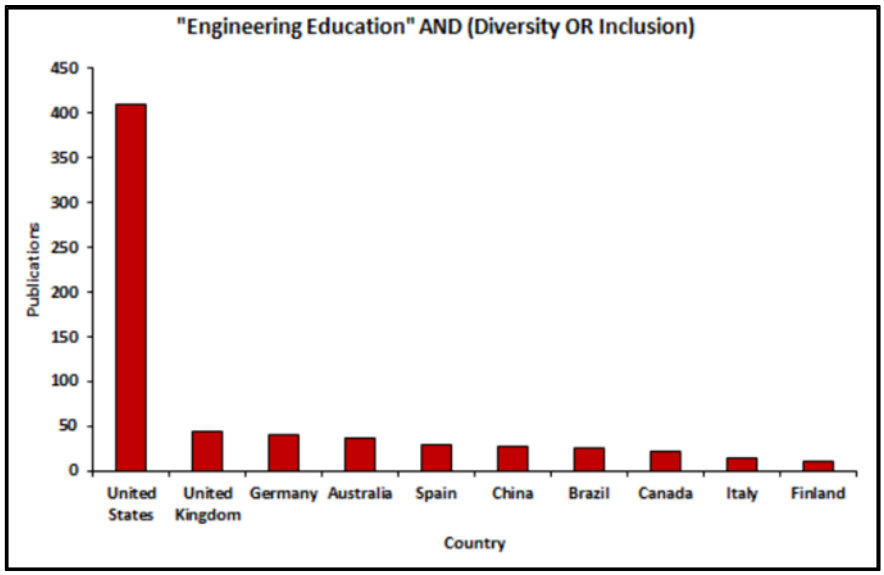
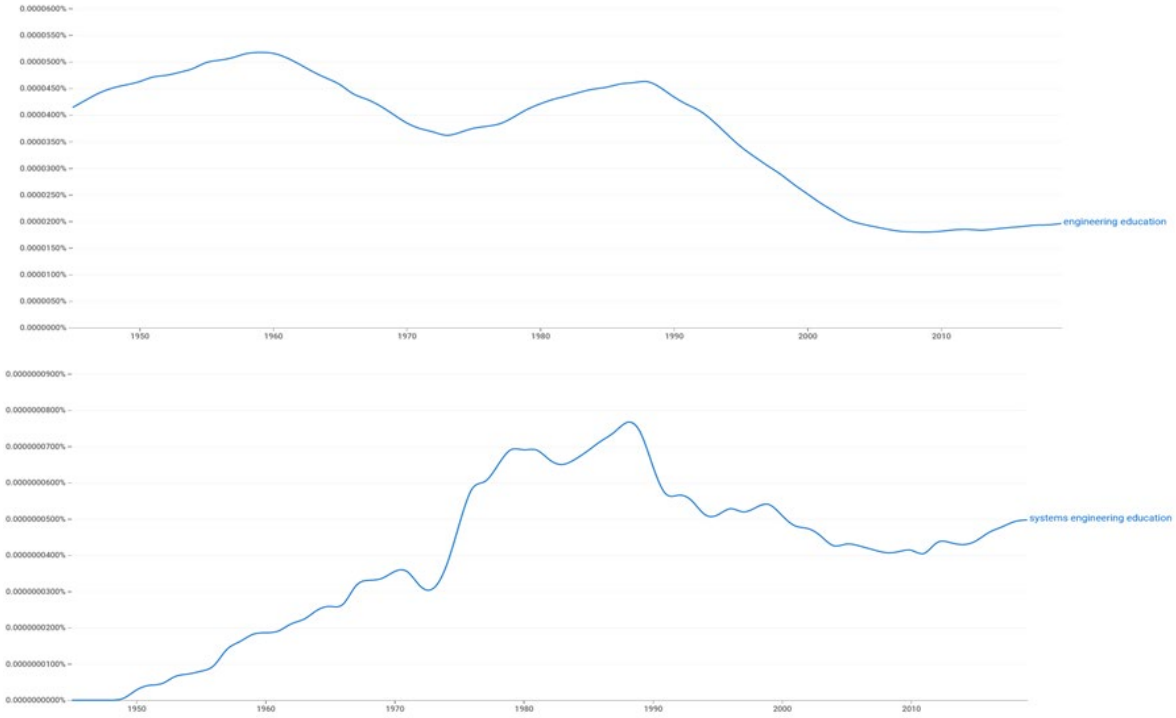


Figure 4: Top Ten Countries for “Engineering Education” AND (Diversity OR Inclusion) Publications

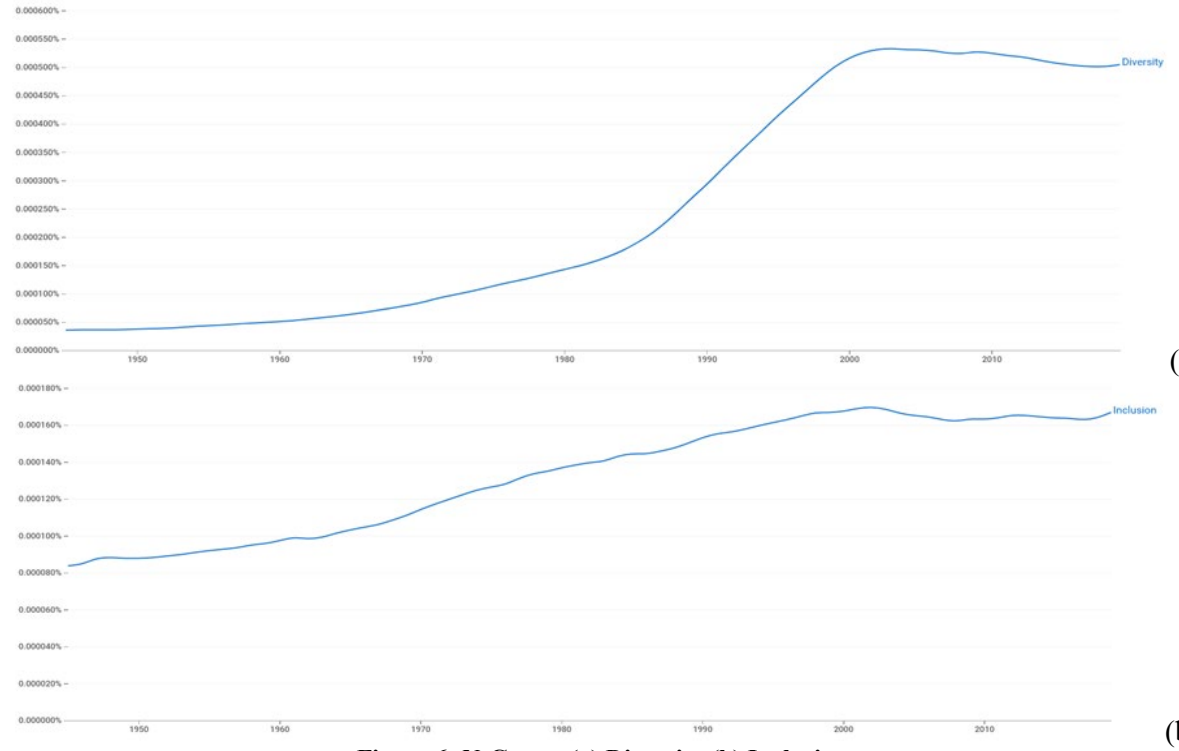
For further analysis, the authors created Figure 5, a Google Books N-Gram of the phrases “Engineering Education” and “Systems Engineering Education.” A Google Books N-Gram search returns the number of times a string of characters used in each year across the corpus of books therein for a specified language, providing an overall pattern of phrase use. In Figure 5, “Engineering Education” appears to have had greater use in the 1940s than in the present with a peak in the late 1950s. An expansion of Google Books N-Gram for “Engineering Education” shows the string first coming into use in the 1800s (not shown). The string “System Engineering Education” came into use in the late 1940s and peaked in the late 1980s. An important pattern in these graphics is the decrease in the use of these strings over time. Figure 6 is also a Google Books N-Gram for the strings “Diversity” and “Inclusion”. The Google Books N-Gram illustrates a general upward trend for both the “Diversity” and “Inclusion” strings. Both strings peaked in the early 2000s and leveled off with a reduced slope.



(a)

(b)

Figure 5: N-Grams (a) Engineering Education (b) Systems Engineering Education



(a)

(b)

Figure 6: N-Grams (a) Diversity (b) Inclusion

A supplemental search through DATAUSA [5] permits the extrapolation of systems engineering education patterns for diversity and inclusion. The DATAUSA website provided some insight regarding “Diversity” and “Inclusion” in “Systems Engineering Education”. Figure 7 illustrates

the ethnicity, race, or non-resident alien status of students earning systems engineering bachelor's degrees. From 2012 to 2019, White students earned most of the systems engineering bachelor's degrees awarded in the United States. The data shows increases in systems engineering bachelor's degree attainment for the following: Hispanic (59.3%), Multiracial (52.6%), Asian (26.8%), Unknown (23.3%), and White (0.6%). The data shows decreases in systems engineering bachelor's degree attainment for the following: Native American (-50.0%), Black (-22.2%), and Non-resident (-21.6%). Pacific Islander systems engineering bachelor's degree attainment had no change.

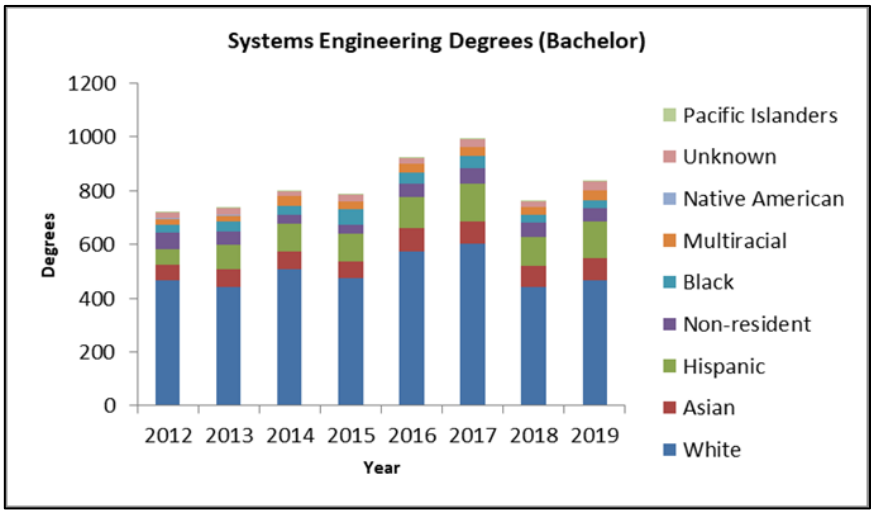


Figure 7: Systems Engineering Bachelor's Degrees (Ethnicity, Race, or Status)

Figure 8 illustrates the ethnicity, race, or non-resident alien status of students awarded systems engineering master's degrees. Again, from 2012 to 2019 White students earned the majority of the systems engineering master's degrees. The data shows increases in systems engineering master's degree attainment for the following: Multiracial (73.7%), Non-resident (35.1%), and Hispanic (10.8%). The data shows decreases in systems engineering master's degree attainment for the following: Pacific Islander (-300.0%), Native American (-150.0%), Unknown (-71.2%), Asian (-32.7%), Black (-26.4%), and White (-8.5%).

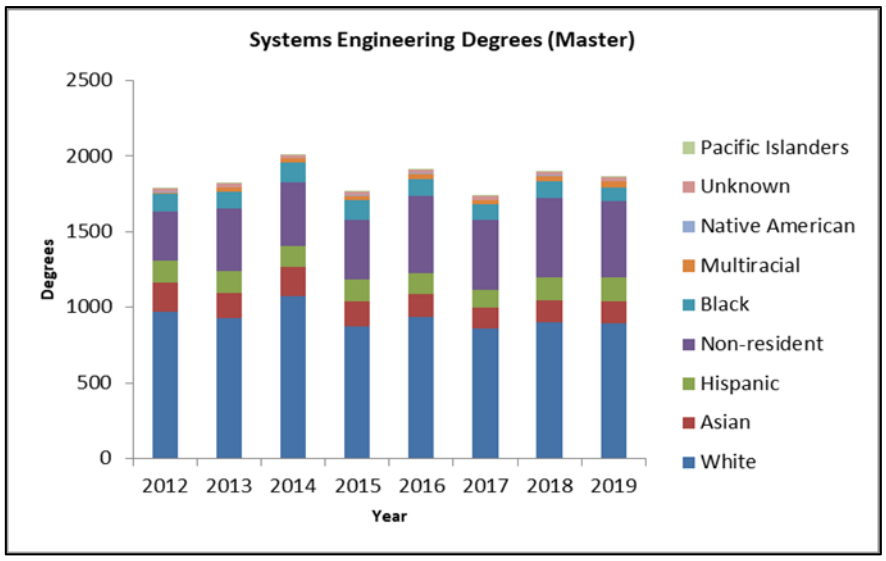


Figure 8: Systems Engineering Master's Degrees (Ethnicity, Race, or Status)

Figure 9 illustrates the ethnicity, race, or non-resident alien status of students earning systems engineering doctoral degrees. Although the data from 2012 to 2019 show White students earn the majority of the systems engineering doctoral degrees, Non-resident students earned a significant number of doctoral degrees. The data shows increases in systems engineering doctoral degree attainment for the following: Hispanic (100.0%), Native American (100.0%), Asian (69.2%), Black (66.7%), Unknown (22.2%), and White (21.6%). The data shows decreases in systems engineering doctoral degree attainment for the following: Multiracial (-100.0%) and Non-resident (-4.7%). Pacific Islander systems engineering doctoral degree attainment had no change.

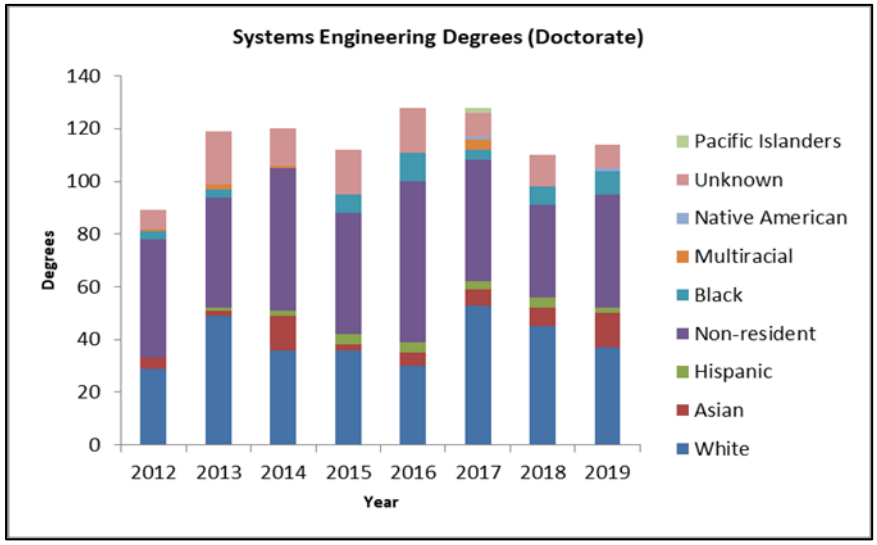


Figure 9: Systems Engineering Doctoral Degrees (Ethnicity, Race, or Status)

Figure 10 illustrates the totality of systems engineering degrees awarded to students by ethnicity, race, or non-resident alien status. Again, from 2012 to 2019 the data shows that White students

earned the majority of the systems engineering degrees. The data shows increases in the total number of systems engineering degrees earned for the following: Multiracial (61.8%), Hispanic (33.6%), and Non-resident (27.4%). The data shows decreases in the total number of systems engineering degrees earned for the following: Pacific Islander (-150.0%), Native American (-60.0%), Unknown (-54.7%), Black (-18.9%), Asian (-7.3%), and White (-4.7%).

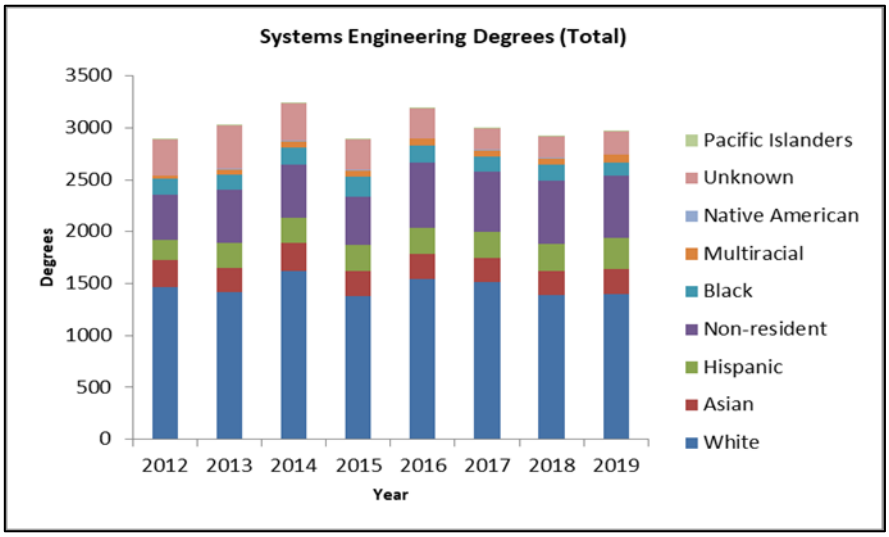


Figure 10: Systems Engineering Total Degrees (Ethnicity, Race, or Status)

Figure 11 illustrates the gender of students awarded systems engineering bachelor's degrees. From 2012 to 2019, male students earned the majority of the systems engineering bachelor's degrees. The data also shows increases in systems engineering bachelor's degree attainment as follows: females (41.1%) and males (2.8%).

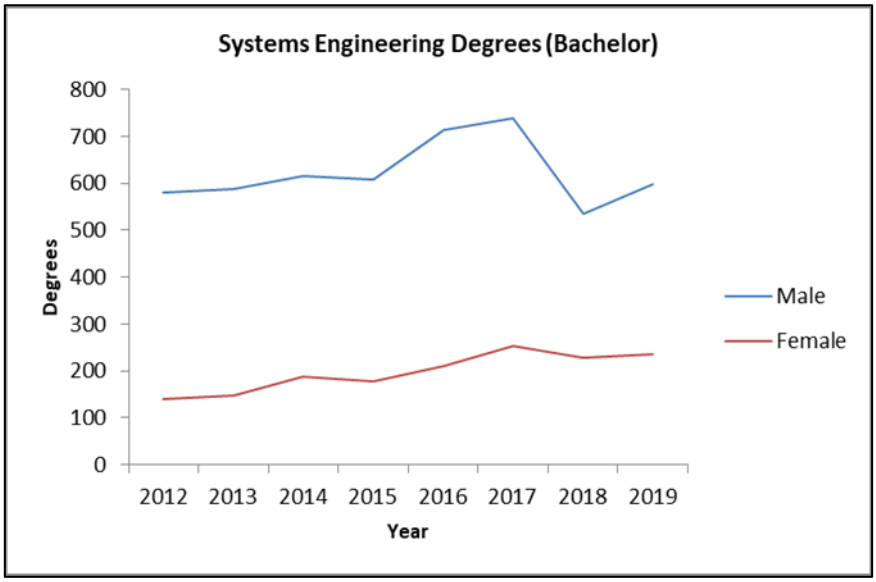


Figure 11: Systems Engineering Bachelor's Degrees (Gender)

Figure 12 illustrates the gender of students awarded systems engineering master's degrees. From 2012 to 2019, male students earned the majority of the systems engineering master's degrees. The data shows an increase in systems engineering master's degree attainment for females (6.3%) and a decrease for males (-6.1%).

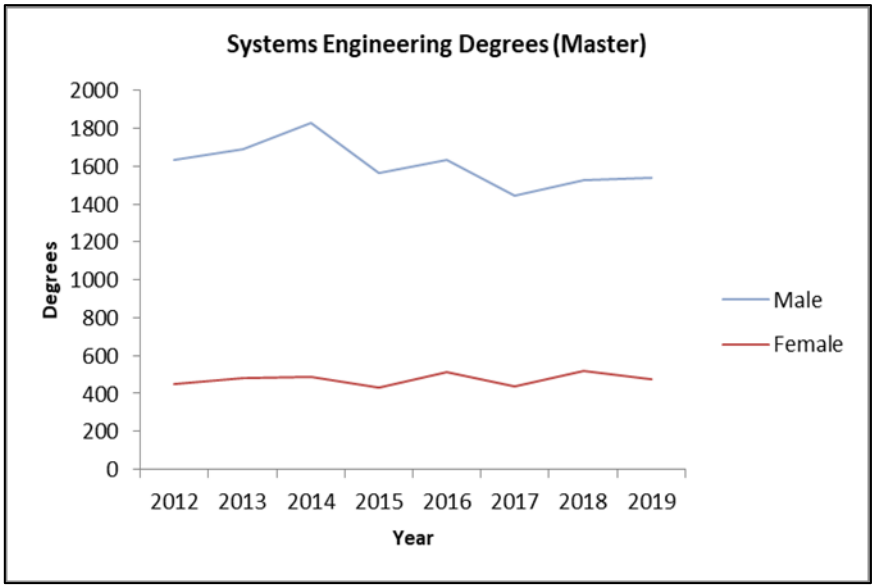


Figure 12: Systems Engineering Master Degrees (Gender)

Figure 13 illustrates the gender of students awarded systems engineering doctoral degrees. From 2012 to 2019, male students earned the majority of the systems engineering doctoral degrees. The data shows increases in systems engineering doctoral degree attainment: males (23.3%) and females (16.7%).

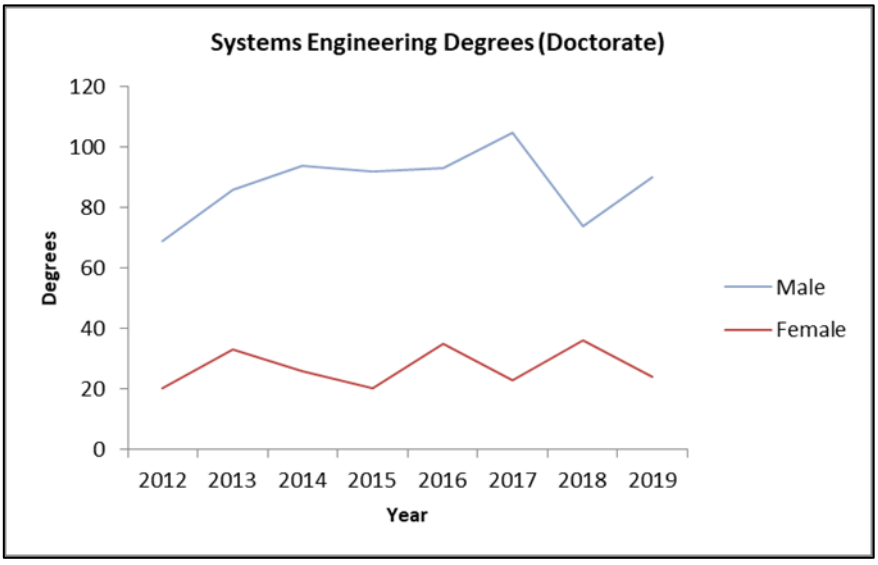


Figure 13: Systems Engineering Doctoral Degrees (Gender)

Figure 14 illustrates the totality of students awarded total systems engineering degrees by gender. From 2012 to 2019, male students earned the majority of systems engineering degrees. The data also shows an increase in systems engineering degree attainment for females (17.3%) and a decrease for males (-2.5%).

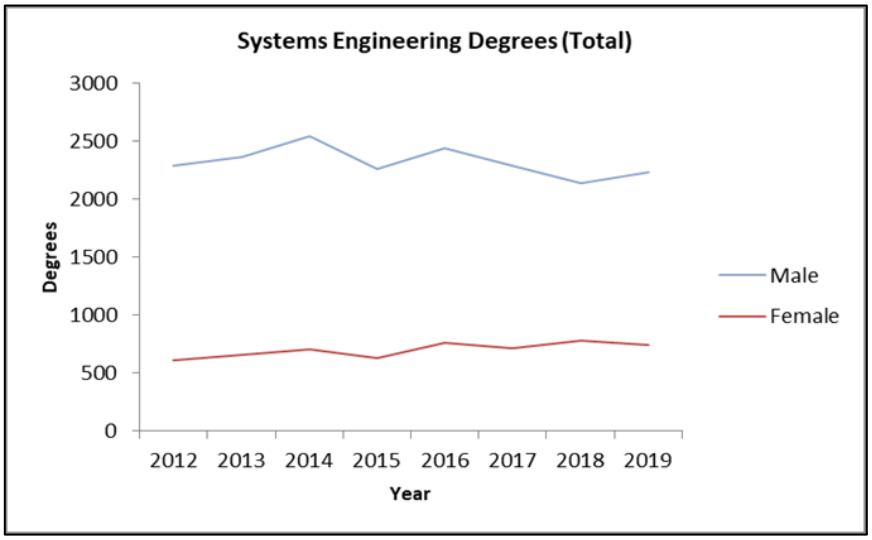


Figure 14: Systems Engineering Total Degrees (Gender)

5. Conclusion & Discussion

The findings presented in this paper illustrate a growing trend in engineering education diversity and inclusion research activity and publications. Counter to this trend was an observed decline in publications in 2020, which coincided with the onset of the COVID-19 pandemic. Future years will determine whether this was an anomaly, caused by the pandemic, or marked a distinct shift in the trend. For the moment, the temporal assumption is the trend for diversity and inclusion research activity and publications will continue to increase.

The United States is by far the most prolific publisher of papers when searching "engineering education" AND (diversity OR inclusion). Purdue and Virginia Tech are two leading institutions in this field. Both institutions award degrees in engineering education, which suggests there are plentiful opportunities for further exploration in this arena.

The Institute of Electrical and Electronic Engineers (IEEE), the American Society of Engineering Education (ASEE), and the European Society for Engineering Education (SEFI) are the leading publishers, as revealed by this analysis. Each of these organizations offers publications that promote engineering education research work, and therefore appear reasonable for both conference and journal publication in this arena. Additionally, the Google Books N-Gram suggests interest in engineering diversity and inclusion has been increasing over the last half-century.

Regarding “Systems Engineering Education”, “Diversity” and “Inclusion”, the DATAUSA website provides awareness of ethnicity and gender within the System Engineering discipline. While the ethnic diversity is inconclusive among the various degrees, students pursuing a systems engineering master’s degree appear to have the greatest diversity. Overall, individuals categorized as Multiracial, Hispanic, and Non-resident showed the greatest increase in degree attainment, while all other categories showed a decrease. This transition in degree attainment deserves further study to understand better the mechanisms driving the inconsistencies in ethnic diversity. Another important transition in systems engineering education involves gender. Females are making inroads into the discipline, and the overall increase in female degree attainment is noticeable. By comparison, enrollment in systems engineering programs by males has seen a rapid decline starting around 2017. The influencing factor for this irregularity is not readily apparent.

Overall, this study enhances the general understanding of diversity and inclusion trends within systems engineering education. However, the study findings elicit many new questions related to diversity and inclusion that remain unanswered. To better understand and establish the determinants/influencers will require studies that are more robust to attract diverse students into the discipline, preparing/training them to be successful engineers, and thereby creating a more heterogeneous workforce in the future.

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