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WOMEN IN MECHANICAL ENGINEERING: THE GENDER (IM)BALANCE BY THE NUMBERS

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ABSTRACT

In this paper, we take a close look at the participation of women in Mechanical Engineering, through an analysis of scientific publications in the field. Using a large dataset of over 100,000 publications from the ASME digital library, the paper creates a picture of the gender preferences associated with areas in the field of Mechanical Engineering. We find that while the average percentage of women in the field is generally low (15.6%), there are significant differences between the percentages of women in different categories, with areas such as biomechanical engineering, energy management, renewable energy, and nanotechnology attracting a larger than average proportion of women. Additionally, we also analyze the change in the number of authors in different areas over 20 years of research in the field, and observe a significant growth in recent years for both genders in the areas of biomechanical engineering, nanotechnology, and computational engineering.

INTRODUCTION AND BACKGROUND

Although the engineering workforce plays a crucial role in the U.S. economy, with the total of 5% of U.S. workers employed in science and engineering areas being responsible for more than 50% of the sustained economic expansion in U.S. [1], women are largely underrepresented in the degrees and jobs in these areas. Recent statistics indicate that only 19% of engineering Bachelor degrees were awarded to women in 2012 and fewer than 20% of enrolled engineering undergraduates were women [2].

A number of reports have also indicated the need to improve the quality of science, technology, engineering, and mathematics education to support a diverse student body and prepare engineers to be competitive in a global work force [3–5]. Research such as the pivotal work of [6] and [7] has demonstrated that, in many cases, faculty teaching practices can greatly affect the quality of education in these fields. Specifically, such practices can have a direct impact on student achievement (e.g., student involvement, engagement, knowledge construction, and cognitive development) and, as a result, on student decisions to persist in engineering [8, 9].

It has been noted that introductory science courses are often responsible for driving off many students who have an initial intention and the ability to earn science degrees but instead switch to nonscientific fields (i.e., students in the second tier) [7, 10, 11]. Women and other underrepresented minorities are over-represented in this population. In [11], several teaching practices are summarized that contribute to the departure of second tier students from engineering. These include a lack of classroom community, a lack of identifiable goals in a course, relegation of students to almost complete passivity in the classroom, and failure to motivate interest in science by establishing its relevance to the students' lives and personal interests. In particular, possible practices to address the gender gap in science and engineering have been identified in a project funded by the National Science Foundation [12], including recruitment practices such as career planning and arousal of interests in a field, positive environment for women and minorities, hands-on workshops, contextualized curriculum that explicitly shows the practical utility

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of topics covered in the courses, mentoring, and role models.

The gender gap has significant implications on progress made in these fields: engineers are responsible for many of the aspects of our daily life including the construction of buildings and bridges; the design of cars, computers, or health-monitoring devices; or the identification of sources of renewable energy but women are often not involved in the development of these products, which can sometimes make them less appropriate for the women consumers. This segregation is also one of the causes for the gender pay inequity, which has broad societal implications considering the fact that most of the single parents are women and that child-care responsibilities fall predominantly on women.

In this paper, we take a close look at the participation of men and women in the field of Mechanical Engineering, through an analysis of scientific publications in the field. We compile a large collection of articles spanning 20 years of publication data (1995-2014). The publications are distributed across 31 categories, drawn from the American Society of Mechanical Engineers (ASME) classification of areas in Mechanical Engineering. Using statistical analyses applied on this data, we obtain several interesting findings. Among others, we find that the percentage of women authors in ME dropped from 21% in 1995, to 10% in 2000, and then it grew back again to 17% in 2014. We also find that areas such as biomechanical engineering, nanotechnology, or computer aided design are of significantly higher interest to women, whereas areas such as electronics and photonics packaging, internal combustion engines, and pipeline and piping systems are clearly dominated by men.

We believe our findings are important not only for reaching a better understanding of the field of Mechanical Engineering, but they can also have implications on recruitment and retention activities that can be made more effective by specifically accounting for the observed gender preferences.

Specifically, the paper makes three important contributions. First, we compile what we believe is the first and largest collection of Mechanical Engineering publications annotated with author gender. In the process, we also explore techniques for automatic gender annotation, which we use to label the gender of the authors in our collection.

Second, we identify the areas that are primarily preferred by men and women. Starting with the collection of Mechanical Engineering publications annotated for gender, we find a set of papers that are assigned to one or more categories using the ASME classification system. We provide data and analysis of the number of men and women who published papers in a set of 31 ASME categories, as well as a grouping of these categories into a coarser set of nine broad categories.

Third, we perform an initial temporal analysis of the trends of these preferences over time, which can provide insight into how interests have shifted with the growth or change associated with specific areas within Mechanical Engineering.

BUILDING A COLLECTION OF PAPERS LABELED FOR GENDER

In order to infer gender interests for the field of Mechanical Engineering, we need a large collection of publications that cover all the Mechanical Engineering areas, and which have their authors annotated for gender. We build our collection using the ASME digital library, and consequently use the ASME categories.

ASME Classification System

Our system of categories is based on the ASME's digital library classification system, which contains 32 large topics. We removed one of the topics, "Careers," for not referring to a domain-specific area, and we therefore used the remaining 31 categories. Table 1 includes a listing of these categories.

We also grouped these 31 topics into nine broad categories by identifying the common themes among the ASME topics. For instance, computer-aided design, computers & information in engineering, and numerical analysis are grouped into one broad category named computational engineering. Table 1 shows these groupings, where each broad category is shown as a header followed by the ASME categories that belong to it.

COLLECTING META-DATA FOR ASME PUBLICATIONS

Starting with the ASME categories, we used the ASME digital collection available online[1] to collect meta-data for all the publications under each category starting with 1995. We collected information on a total of 100,257 publications. For each paper, we extracted several pieces of information, including the title, the authors, the institution of the authors, the abstract, and the categories to which the publication belongs. Note that one paper typically belongs to multiple categories. Table 1 lists the total number of papers included in each category.

FINDING THE GENDER OF A NAME

A critical piece of information required by our work is the gender of the authors of the research papers in the collection. Thus, an important challenge that we faced was the identification of the gender of the author names. While this may be a relatively trivial task for names for which there is a good Census data (e.g., American names), the problem becomes significantly more challenging when the names spread a large number of cultures as is the case with the authors of the ASME publications.

The entire dataset consists of 232,194 authors, with 29,640 unique first names. Given the large number of names in our collection, full manual annotation is not an option, and therefore we used a combination of techniques including online gender analytics services. The abbreviated/single letter first names are ignored and the annotation for the rest is done in three phases. In each

[1] http://asmedigitalcollection.asme.org

TABLE 1. THE ASME CLASSIFICATION SYSTEM

Category	Papers
Biomechanical engineering	
Biomechanical engineering	13,359
Computational engineering	
Computer-aided design (CAD)	7,340
Computers & information in engineering	6,563
Numerical analysis	3,134
Design and manufacturing	
Manufacturing & processing	10,606
Nondestructive evaluation	1,657
Design engineering	11,598
Pipeline & piping systems	3,093
Tribology	7,053
Boilers & pressure vessels	11,517
Building & construction	3,770
Energy and thermo-fluids	
Energy	21,777
Energy technology management	2,217
Fluids engineering	22,086
Heat transfer	8,893
Renewable energy	1,594
Internal combustion engines	4,999
Conventional power & fuels	4,459
Nuclear engineering	2,007
Electronics, robotics and control	
Dynamic systems & control	9,464
Robotics & mechatronics	4,459
Electronic & photonic packaging	3,670
Environmental engineering	
Ocean, offshore & arctic engineering	1,726
Environmental engineering	2,421
Industries	
Automotive systems	3,810
Transportation	1,141
Aerospace industry	4,886
Defense industry	3,070
Nanotechnology	
Nanotechnology	2,037
Mechanics	
Applied Mechanics	62,522
Noise Control & Acoustics	3,379

phase the predicted gender is also assigned an accuracy estimate on a scale of 0.0 through 1.0 as provided by the gender analytics services.

Phase I: In the first phase we make use of the dataset from **Tang et al** [13], who used the Facebook public profile pages of a large and diverse user population in New York City to compile a list of names along with gender and popularity estimates. For the names classified by the Tang heuristics we assign a scale of 1.0 as we consider them to be accurate classifications. Around 6000 names were annotated in this phase.

Phase II: For the remaining names we use **Genderize**,[2] a gender analytics API having a database of 90,560 distinct names across 78 countries and 89 languages. The API response returns the most frequent gender for a name alongside a confidence factor that is recorded as the scale for the prediction.

Phase III: In the third phase we make use of another API, **NamSor**,[3] which also returns the gender of a requested name with a scale value that reflects the confidence of their gender assignment. In the cases where Namsor predicts the gender of a name with a higher confidence than what we already have from the previous phase, we update the recorded scale for that name. If the response for a particular name has a different gender with a scale higher than the pre-recorded scale, we update both the gender and the scale.

[2] http://genderize.io
[3] http://www.namsor.com/

For all the gender annotation phases, we only consider names for which the prediction accuracy (scale) is higher than 0.4. At the end of the three phases, we have confidently determined the gender of all but 8,204 unique first names. The set of unlabelled names consists of rare or ambiguous names and accounts for less than 4% of the total dataset of authors. The authors corresponding to the unlabelled names are ignored in the analysis process.

Table 2 shows ten randomly sampled male and female names from our final dataset.

TABLE 2. SAMPLE NAMES LABELED BY GENDER

Name	Annotated Gender
François, Gérard, Satish, Yong, Matthias, Qiang, Zoltán, Damian, Iman, Kazuo	Male
Maria, Michele, Tracey, Madhura, Andrea, Becky, Archana, Xuping, Cornelia, Isabel	Female

We also performed a manual verification of the gender annotation results by picking 100 different names at random and then accessing the author's personal web page or information provided by the university or institution they worked with to determine the gender. This evaluation resulted in an accuracy rate of our automatic predictions of 92%, which we believe is within reasonable limits, and therefore we use our automatic annotations to proceed with the data analysis.

GENDER IN MECHANICAL ENGINEERING

The final dataset used for our gender analyses consists of 100,257 papers, assigned to 31 categories which in turn are divided into nine broad categories, with 232,194 authors including 195,819 males and 36,375 females. This gender distribution leads to a "baseline" distribution of 15.6% female over the entire dataset.

MALE AND FEMALE AUTHORS

Our first analysis consists of a plot of the number of authors by gender over time and a plot of the number of total publications by gender over time. Figure 1 shows the absolute number of males or females that had a publication in a certain year, starting with 1995, and ending with 2014. Figure 2 shows the absolute number of publications that had a male or a female as an author during the same time interval. Since our data collection took place toward the end of 2014, the number of authors and publications for 2014 are incomplete.

Overall, the number of publications grows over time for both males and females, which corresponds to a growing number of authors publishing in Mechanical Engineering.

Figure 3 shows the percentage of females among all the authors.[4] We notice that the percentage of female authors slowly increases over time, although we do see some fluctuation between 1995 and present. This includes a large spike around 1995, representing prominent female publications of that time.

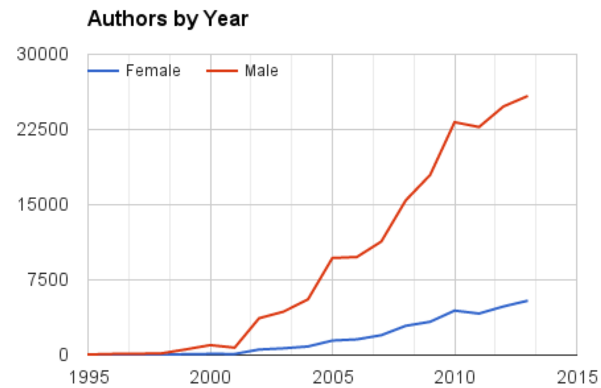

FIGURE 1. NUMBER OF AUTHORS BY GENDER BY YEAR

GENDER PREFERENCES

To understand the preferences that genders have toward certain categories, we calculate the percentage of female authors in each of the categories used in our paper collection. Note that although a paper can be assigned to multiple categories, for the purpose of these analyses, we consider all the categories equally.

We first analyze the percentage of female authors on publications belonging to the nine broad categories listed in Table 1. Table 3 shows the percentage of female authors in each of these categories. We also calculate the significance of the results using a binomial cumulative distribution function. The categories for which the difference with respect to the average over the entire collection is significant with $p < 0.05$ are marked with a (*).

Biomechanical engineering and nanotechnology have the highest percentage of female authors. These categories have a clearly larger fraction of female authors as compared to the other categories, although the highest of the nine categories still only contains 23% female authors.

[4]For obvious reasons, whenever we calculate percentages, we only need to report the numbers for one gender, as the other gender can be inferred by subtracting from 1. Throughout this paper, percentage calculations refer to female percentages.

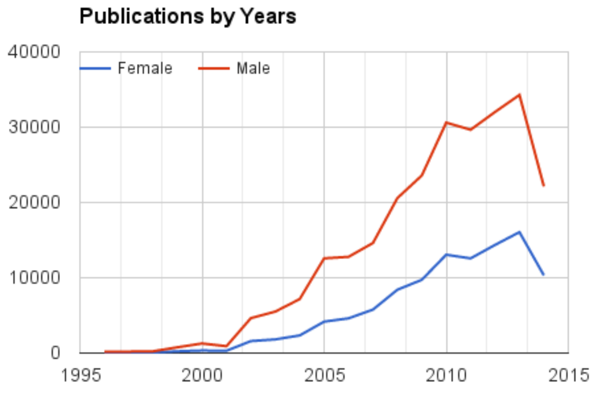

FIGURE 2. NUMBER OF PUBLICATIONS BY GENDER BY YEAR

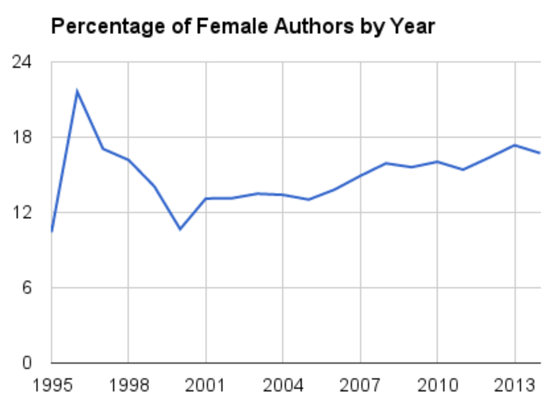

FIGURE 3. PERCENTAGE OF FEMALE AUTHORS BY YEAR

We then repeat the same analysis, but this time using the 31 main ASME categories. Table 4 shows the percentage of women authors in each of these categories.

While to our knowledge this is the first time that the gender interests in Mechanical Engineering areas are objectively quantified, the findings are intuitive and inline with previous sociological research, which suggested that women tend to prefer areas that have a strong applicative component, are human-centered, or have a clear social aspect [14].

In particular, women seem to have increased interest in biomechanical engineering, which is an area with tight connections to biology and health. Energy management and reneweable energy are two areas that also attract a higher than average number of women, which may be explained by the potentially positive impact that renewable energy can have on society. It appears that areas related to design, such as computer-aided design and design engineering, are also of higher interest to women.

TABLE 3. PERCENTAGE OF FEMALE AUTHORS IN NINE BROAD CATEGORIES

Category	Female
Biomechanical engineering	22.9%*
Nanotechnology	18.9%*
Computational engineering	16.7%*
Environmental engineering	16.2%
Mechanics	15.0%*
Energy and thermo-fluids	15.0%*
Design and manufacturing	15.0%*
Electronics, robotics and control	14.8%*
Industries	14.8%*
Micro-average over entire collection	15.6%

GENDER INTERESTS OVER TIME

Using our collection of papers, we can also look at publication dates to determine how the number of publications per gender in each category changes over time. For this analysis, we use the nine broad categories, as shown in Table 1. The graphs in figures 4 and 5 show number of publications in each category for female and male authors respectively. The overall curve shapes for the different categories seem to follow similar trends for males and females, with a decline in recent years in the number of publications in the area of mechanics, but significant growth in the areas of biomechanical engineering, nanotechnology, and computational engineering. Other areas, such as energy and thermo-fluids, or electronics, robotics, and control, while having their own periodical peaks, appear to be more uniform over time. Among the nine broad categories, biomechanical engineering and nanotechnology experience significantly sharper growth curves for female authors, which is in line with our earlier finding that women have a larger than average interest in these two areas.

CONCLUSIONS

Our findings suggest that there are areas in Mechanical Engineering that are clearly preferred by women, with a significantly larger fraction of women publishing in these areas as compared to the other areas that are more strongly dominated by men. In particular, we found that biomechanical engineering and nan-

TABLE 4. PERCENTAGE OF FEMALE AUTHORS IN 31 MECHANICAL ENGINEERING CATEGORIES

Category	Female
Biomechanical engineering	22.9%*
Energy technology management	19.7%*
Renewable energy	19.7%*
Nanotechnology	19.0%*
Computer-aided design	17.4%*
Design engineering	17.0%*
Robotics & mechatronics	16.6%
Building & construction	16.4%
Computers & information in engineering	16.3%
Ocean, offshore & arctic engineering	16.0%
Numerical analysis	15.9%
Nuclear engineering	15.9%
Environmental engineering	15.9%
Conventional fuels & power	15.7%
Energy	15.6%
Heat transfer	15.4%
Applied mechanics	15.2%*
Dynamic systems & control	15.1%
Transportation	15.1%
Nondestructive evaluation	14.8%
Defense industry	14.7%
Fluids engineering	14.6%*
Aerospace industry	14.6%*
Automotive systems	14.3%*
Noise control & acoustics	14.3%*
Tribology	14.3%*
Pipeline & piping systems	14.2%*
Boilers & pressure vessels	14.1%*
Manufacturing & processing	14.1%*
Electronic & photonic packaging	13.3%*
Internal combustion engines	9.6%*
Micro-average over entire collection	15.6%

otechnology are the two broad categories preferred by women, with computational engineering also having a larger than average percentage of women.

Zooming in, we were also able to identify more specific categories that seem to raise the interest of women, including areas such as energy technology development, reneweable energy, computer-aided design, and design engineering (in addition to biomechanical engineering and nanotechnology).

We were also able to identify areas where the percentage of women is significantly lower than the average, including internal combustion engines, electronic & photonic packaging, manufacturing & processing, boilers & pressure vessels, pipeline & piping systems, and others.

While there could be a wide variety of factors behind the success of publishing in various Mechanical Engineering categories, we believe our findings are to some degree telling of the interests of men and women in this field. In the future, we plan to diversify our data sources, and also include writings from earlier stages, such as students taking introductory courses in Mechanical Engineering, or students who have not been exposed to Mechanical Engineering.

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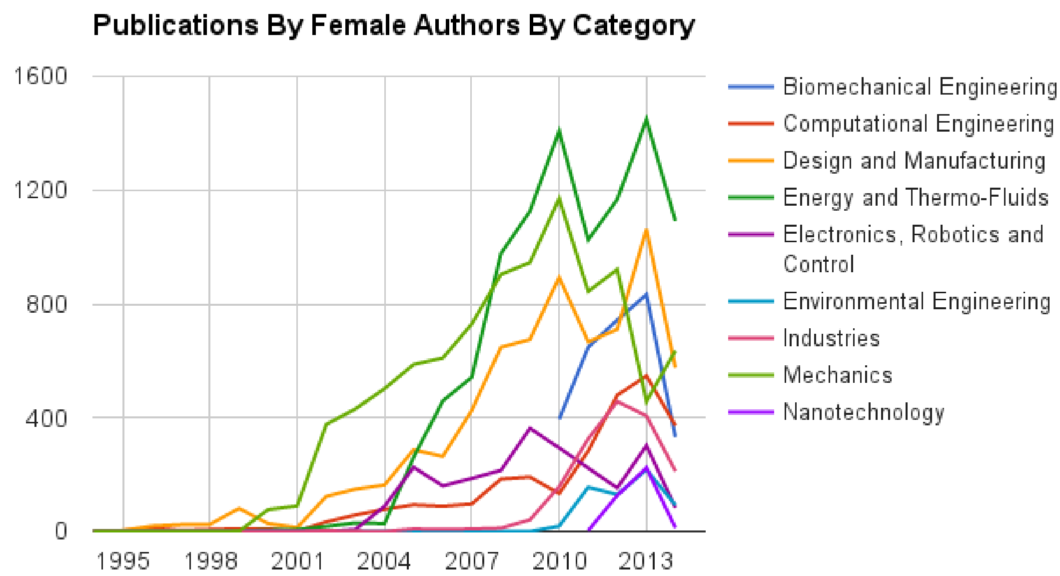

FIGURE 4. PUBLICATIONS BY FEMALE AUTHORS BY TOPIC BY YEAR

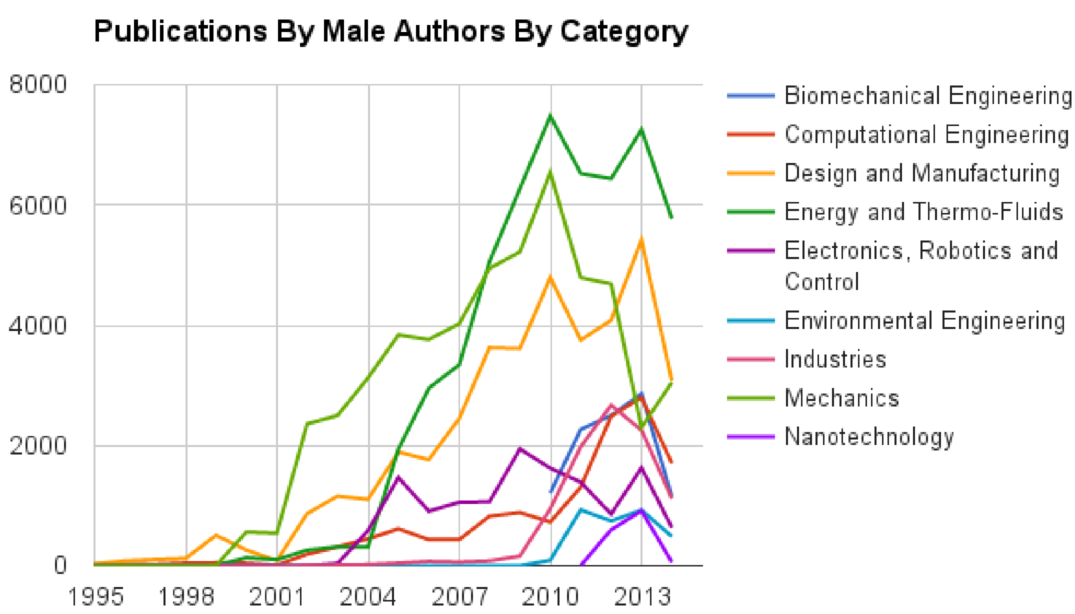

FIGURE 5. PUBLICATIONS BY MALE AUTHORS BY TOPIC BY YEAR

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