Fab Lab-Based Learning and Gender Gap in North America

Pablo C. Herrera
Facultad de Arquitectura
Universidad Peruana de Ciencias Aplicadas
Lima, Peru
0000-0001-8535-2029

Macarena Valenzuela-Zubiaur
Departamento de Diseño
Universidad Tecnologica Metropolitana
Santiago, Chile
0000-0003-3199-8355

Vaneza Caycho
Postgraduate School
Universidad Nacional Federico Villarreal
Lima, Peru
0000-0001-6844-4810

MariLú Pineda-Gutierrez
Facultad de Arquitectura
Universidad Peruana de Ciencias Aplicadas
Lima, Peru
0000-0001-9451-0762

***Abstract*— In this quantitative research, we analyze the geographic distribution and gender gap of women graduates from a Fab Lab-based learning environment across IEEE Regions 1-7 in North America. The United States (Regions 1-6) contributed 10% (N=143) of the women graduates, while Canada (Region 7) contributed 1% (N=11) across 26 Fab Academy nodes out of 324 Fab Labs in Regions 1-7. The study includes 49 women graduates from 2 countries between 2009 and 2023, out of 154 graduate students. These results are compared to the total Fab Academy graduates by gender (N=1,433) for IEEE Regions 8-10 (Europe, Africa, the Middle East, Latin America, Asia, and Oceania). The United States has the highest number of women graduates in the Fab Academy universe at 33%, followed by Region 8 (30%), Region 10 (23%), Region 9 (20%) and Region 7 (18%). The study provides quantitative evidence supporting previous qualitative initiatives, where Fab-Lab-based learning directly and positively impacts a greater number of women who acquire STEM skills.**

Keywords— Fab Lab-based, North America, Gender, Women in Engineering, Fab Academy

I. Gender Gap and Women in Engineering

There is a growing interest in studying the gender gap in Science, Technology, Engineering, and Mathematics (STEM) [1]. However, it is necessary to identify and analyze a distributed, global, and structured learning ecosystem that includes different initiatives to include women in engineering. This will allow for a comparison of the gender gap in different geographical contexts. This is why we investigated a global program that implements a methodology in IEEE Regions 1-10.

Quantitative global statistics report consistent tracking of the gender gap across economy, politics, health, and education [2]. Engineering is no exception to this gap as evidenced by the Society of Women Engineers [3] Meiksins reports, IEEE Women in Engineering, and ACM-W initiatives for over a decade.

Quantitative research on gender in STEM is not a new topic, but it accumulates significant challenges. Reference [4] argues that measurement and labeling of big data on gender is limited, particularly in bibliometric studies where authors do not self-determine their gender status. In this context, geo-referencing considers the institution as the place of study or work, but there is no record of geographic origin. A second problem of measurement, is the absence of data in reports of institutions linked to engineering, because they include unprocessed data sets and without representative samples that expand details of environments such as professional social networks [5]. A third problem in the massive analysis of gender data in engineering is the disparity in which institutions organize, create, and store their data. This is exacerbated by political or managerial circumstances of institutionalization of initiatives such as curricular plans, structural complexity of engineering disciplines. Reference [6] argues that this complicates the analysis because indicators, criteria, and dimensions are not applied to institutions within the same database.

In academia, two other challenges related to the sustainability of initiatives over time need to be understood in order to comprehend the evolution of the gap. Since 2005, the European Union has funded universities' research to understand the participation of women in engineering.

The HELENA program (2009-2011) compared traditional and interdisciplinary programs and their impact on women's participation [7]. Hence, the list of funded initiatives is extensive and includes WOMENG (2002-2005), PROMETEA (2005-2007), GARCIA (2014-2017), genSET (2009-2012), FESTA (2012-2017), Genis Lab (2011-2014), and EGERA (2014-2017) among others. The main challenge of these initiatives is academic diversity. This is because the university not only influences the sustainability of the initiatives but also the political approaches of the countries. Not all are willing to create monitoring and evaluation tools at the institutional level, and in many cases, they do not achieve a systemic transformation that demonstrates significant changes in the short or long term in the gender gap [8].

We are investigating the gender gap within a program with a defined curriculum and distributed learning using a problem-based learning approach. We conducted an analysis on a total of graduates (NG=1,433) [9] from a global program who graduated between 2009 and 2023. Specifically, we focused on the 154 graduates from IEEE Regions 1 to 6 (USA) and 7 (Canada).

A. IEEE Education Society Conferences and Gender

Education and technological excellence has been led by five flagship conferences with the sponsorship of the IEEE Education Society (EdSoc). In our research, we have chosen to focus on four of specific conferences: Frontiers in Education (FIE) in United States and Canada (Regions 1-7), IEEE Global

Engineering Education Conference (EDUCON) in Europe, Middle East, and Africa (Region 8), IEEE World Engineering Education Conference (EDUNINE) in Latin America and the Caribbean (Region 9), and IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE) in Asia-Pacific (Region 10). In this research, we refer to the location of the case studies using either the region number (e.g., IEEE Region 6), the acronym of the EdSoc conference, or the name of the sub-regions (e.g., USA or Canada).

To understand the advancement of the study of gender in engineering in the context of education, we analyzed the total conference papers (N=11,186) from the four conferences hosted in the IEEE Xplore database [10], and used its search engine updated in 2018 with an algorithm that improves extracting details from the metadata. The percentage contribution of conference papers from FIE between 2010 and 2023 is 52% (N=5,822), EDUNINE between 2017 and 2023 is 4% (N=465), EDUCON between 2010 and 2023 is 29% (N=3,297), and TALE between 2012 and 2023 is 14% (N=1,602).

B. Gender and STEM

Gender representation in EdSoc conferences is higher in the northern hemisphere compared to the southern hemisphere. The percentage of gender-related conference papers in the FIE conferences is 5.82% (N=339) and 3.87% (N=126) in EDUCON. These percentages are higher compared to EDUNINE and TALE, with 2.37% (N=11) and 2.25% (N=36) respectively.

In the 339 FIE conference papers, each article had a maximum of ten keywords. The term "gender" is the most frequently used author keyword in the metadata of the articles. It appears in 30% (N=101) of the articles. Specifically, 6% (N=20) of articles have "gender" as the first keyword, 8% (N=27) have it as the second keyword, and 7% (N=24) have it as the third keyword. The remaining 9% is distributed among the fourth to the tenth positions.

Despite the amount of evidence on Gender in the four flagship conferences, the percentage of conference papers between 2010 and 2023 is only 4.36% (N=488). The contribution of FIE conference papers on gender is the highest over other EdSoc conferences.

C. Women in Engineering (WIE)

The participation of women in engineering-related fields has not been the same over the last seven decades. Reference [11], citing Nathan Ensmenger, argues that "at its origins, computer programming was a largely feminized occupation." And that cultural changes in the 1980s led to the current gender bias in computing. The situation today is different from its origins. In the IEEE context, "only about 12% of IEEE Members (other than students) are women"[12].

The FIE conferences evidenced efforts by computer science and engineering educators and researchers to promote diversity and inclusive practice, with various techniques including dynamic mixed group work environments [13], project-based learning, goal-oriented community programs [14], etc.

However, studies on the gender gap in engineering can be validated in contexts that include different dimensions but in the same learning environment, and so far evaluated separately, including implementation methodology, infrastructure and mentoring. In the following section, we evidence a context that brings together several dimensions that promote diversity in STEM [15] in a local, and global context.

D. Fab Lab-based Learning

IEEE EdSoc Keynote Conference, evidenced the disruption of the Fab Lab phenomenon in engineering [16]. Therefore, research contribution in IEEE is very low. To evidence the need for research on this phenomenon, we conducted a bibliometric analysis of IEEE EdSoc conference papers (2010-23) on the STEM topic which is 10.4% (N=1,164) of the total (N=11,186) [10].

In the dataset, we found that the topic of Fab Lab was discussed in conferences from 2017 to 2023, contributing 0.04% (N=5) of the total papers, while the topic of Makerspace, which was discussed in 2013, contributed 0.58% (N=65). In the FIE conferences, the STEM contribution was 13.46% (N=813) and is the conference with the highest contribution (70%) in this topic of all conferences. FIE was the first conference to address the topics of Fab Lab (2017) and Makerspace (2013). By 2023, only 0.05% (N=3) of conference papers were dedicated to Fab Labs, while 0.70% (N=41) were focused on Makerspaces.

Constructivist learning theory and the shared use of digital fabrication in makerspaces and fab labs have led to confusion when referring to the concept of learning in these environments. Reference [17], argues that they converge in a similar structure and use, therefore, there is a discussion on whether to treat them as distinct or similar. Reference [18], points out from the distinction, that Fab Labs are associated with sophisticated machines whereas makerspaces are not necessarily linked with such advanced technology. However, authors identifying similarities find certain characteristic that connect the two.

Reference [19], does not differentiate between the infrastructure, but rather the creative context that exists in both environments, therefore, they are considered the same. Reference [20], also does not distinguish the environments, but rather focuses on the ability to perform a set of tasks centered around "Exploration and Fabrication Technologies".

However, when we refer to a learning environment, the similarity arguments have differences. Learning in Makerspace is linked to different methods on how to achieve learning [21], and different learning settings environments such as children's museum, public library, college education, etc [22]. Its dissemination is driven through Maker Fair and the process and outcome depends on the institution that promotes it, but in general it is not public information.

The Fab Lab (Fabrication Laboratory) concept originated in the course MAS.863 "How to Make (Almost) Anything" at the Massachusetts Institute of Technology (MIT) in 1998 [23]. Over the past ten years, women have consistently participated in the program. In the online archives of MIT's FAB CBA [24], [25], [26] the presence of women was always around 30%.

In 2008, the program evolved into a globally distributed learning initiative known as Fab Academy (FA). Graduates are

This paper is funded by the Dirección de Investigación, Universidad Peruana de Ciencias Aplicadas. UPC-EXPOST-2024-2

required dedicate between 16 to 40 hours per week, totaling 658 hours over the 23.5-week program [27].

Fab Academy program is administered by Fab Foundation and includes infrastructure requirements [28], detailed in the Fab Academy Handbook [29]. Another relevant requirements are instructors (novice, junior, senior), and mentors/gurus who follow the Instructors Handbook [30].Finally, the assessment process [31] is unique for all Fab Academy Nodes.

E. Fab Academy in a Global context

Two previous studies analyzed Fab Academy graduates from 2009 to 2021 in IEEE Region 8 (Europe, Middle East, Africa) [32], and from 2009 to 2023 in IEEE Region 9 (Latin America) [33]. However, out of the total of 1,433 graduates between 2009-23, the US was considered as a single region and not the particularity of its IEEE US Regions 1-6.

This research analyzes the number of women graduates and their distribution in each of the IEEE Regions 1 to 6 (United States), and IEEE Region 7 (Canada), in order to compare the presence of North American women and their peers in the other continents.

Figure 1 shows the distribution by region, which for the first time includes graduates in total IEEE US Regions: US Northeastern (Region 1), US Eastern (Region 2), US Southeastern (Region 3), US Central (Region 4), US South Western (Region 5), and US Western (Region 6).

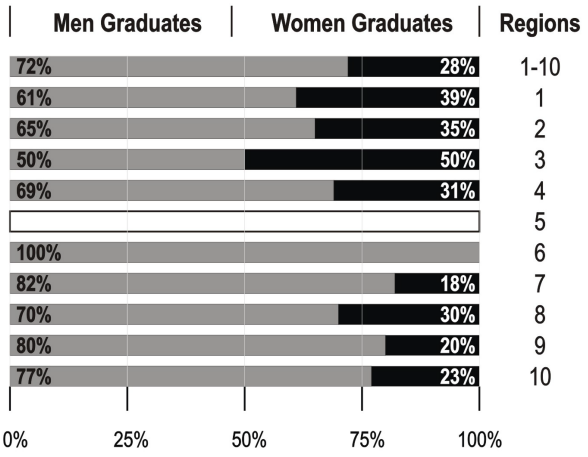

Fig. 1. Percentages Distribution. Fab Academy Graduates by gender for the IEEE Regions 1 to 10.

II. METHODS

This is a quantitative study, which discards qualitative validation [34]. We use empirical research methodologies [35], to obtain data from websites [36], and social networks to map the number of women graduates in the context of the Maker Movement [37], and specifically in the Fab Foundation's Fab Academy program.

For this research we used three public data sources supported by Fab Foundation. The total number of Fab Labs [38], the total number of Fab Academy graduates [9] and the total of Fab Labs Nodes where the graduates studied [39].

The only global program with Fab Academy characteristics that meets the eligibility criteria is the Fab Foundation graduate database. This database is the primary source for the list of graduates between 2009 and 2023, as well as their place of graduation (Fab Academy Node).

A. Fab Lab and Fab Academy Nodes Sources

It's important to note that only Fab Academy Nodes are allowed to teach the Fab Academy program. Fab Labs not affiliated with the Fab Academy can offer different workshops and aren't obligated to adhere to the Fab Academy guidelines. This means we cannot include additional Fab Labs or graduates in our analysis because we are working exclusively with the universe of Fab Academy Nodes

The population of Fab Labs in the world is NFL=2,536 [38]. The number of Fab Labs in Regions 1 to 6 is NFL=282, and in Region 7 is NFL=42. Given the number of regions and states from regions 1 to 6 that belong to the United States, we analyze the number of men and women graduates [9] by location. Therefore, we describe the screening model of those US Fab Labs excluded/included in our research (Figure 2).

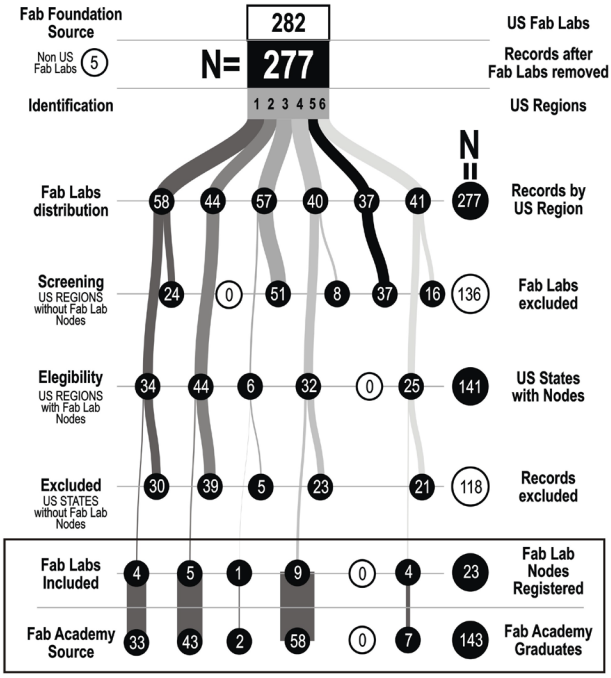

Fig. 2. Fab Labs exclusion flow model and its distribution by US Region and US States with Fab Academy Nodes and Graduates.

Of the 282 Fab Labs in the JSON-formatted database [37], we discarded those not located in the United States (NFL=5). The remaining ones (NFL=277) were distributed across the six regions. We excluded Fab Labs in US Regions that do not have a Fab Academy Node (NFL=136) [39] (Fig. 2). We identified the US States where Fab Academy Nodes are located.

The United States has a total of NFL=141 Fab Labs in US Regions with Fab Academy Nodes. In Figure 3, we present a summary of the screening process. We excluded all Fab Labs that are not Fab Academy nodes in the United States (NFL=118) and Canada (NFL=39), and only retained Fab Academy nodes in regions 1, 4, 6 (NFA=23), and 7 (NFA=3).

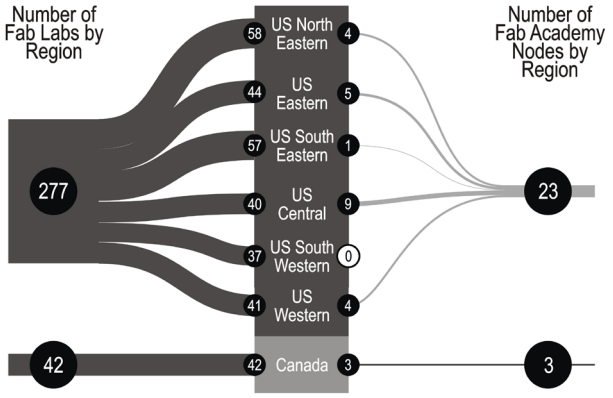

Fig. 3. Number of Fab Labs (NFL) and Fab Academy Nodes (NFA) by US Regions (Regions 1 to 6) and Canada (Region 7).

In Figure 4, we show our analysis in the geography of IEEE Regions 1 to 6 as evidence for the discussion.

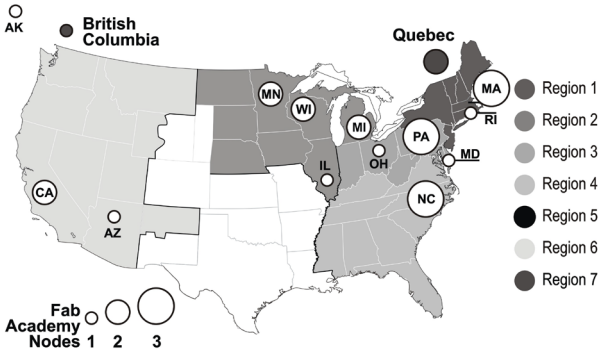

Fig. 4. Distribution of Fab Academy Nodes in the geography of Regions 1 to 7.

Regions were not the only source. For the analysis we fragmented the regions into US States (Fig. 4), and identified those States that had women graduates. Thus, we included thirteen US States in the Fab Academy Nodes and graduates.

B. *Fab Academy Graduate Source*

In this section (Fig. 5), we will provide context for the global distribution of Fab Academy graduates (NG=1,433). The United States (Regions 1 to 6) contributes 10% (NG=143), and Canada (Region 7) contributes 1% (NG=11). Furthermore, we have identified the contribution of each region as follows: Northeastern (Region 1) with 2.3% (NG=33), Eastern (Region 2) contributes 3% (NG=43), Southeastern contributes 0.1% (NG=2), Central contributes 4% (NG=58), Southwestern 0% (NG=0), and Western 0.5% (NG=7).

From the number of graduates (NG=143) from regions 1 to 6, we obtained the distribution of women graduates (NWG=47). The same was for Canada (NG=11) and women graduates (NWG=2) (Fig. 6). The percentages of women's graduates were compared with other regions in Figure 1.

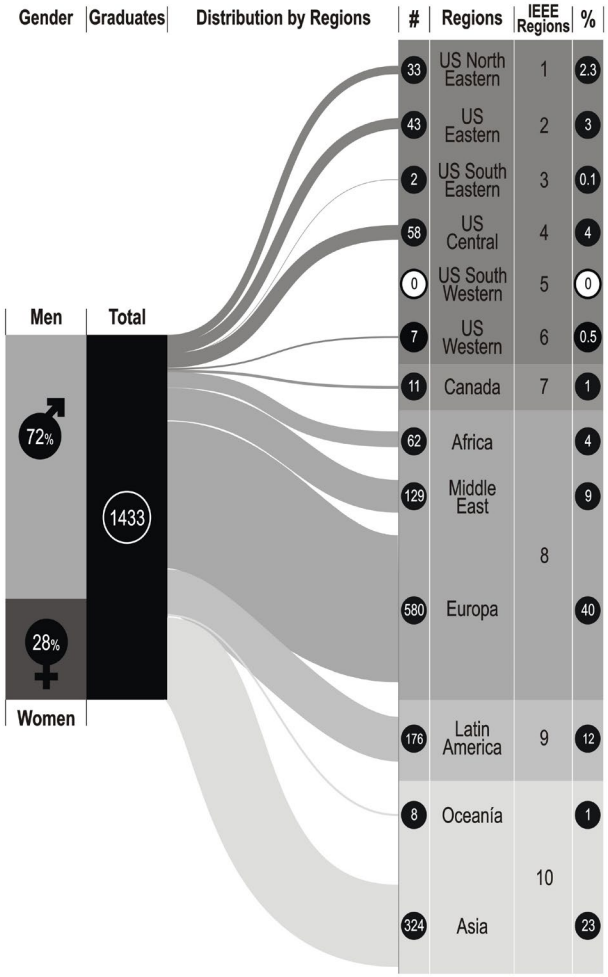

Fig. 5. Distribution by number and percentage of Fab Academy Graduates (NG) for the IEEE Regions 1 to 10.

C. *Gender Identification*

In our study, we examined the gender gap in a learning environment with a structured curriculum and problem-based learning approach. We analyzed data from a total of 1,433 graduates who completed the program in 10 IEEE Regions, between 2009 and 2023, with a specific focus on the 154 graduates from IEEE Regions 1 to 6 (USA) and 7 (Canada).

With respect to gender identification, there is no historical statistics on sex and gender for all graduates in Fab Academy program [9], and this produces limitations [4].

The profiles of each graduate are public and include the project process log as well as a profile photo [40]. However, not all graduates have a portrait included in their profiles, making inference difficult. The second inference filter involved checking for portraits in their profiles on Online Social

Networks (OSNs) [41] and Social Networking Sites (SNSs) [42]. To further secure our inference, a third filter was used. Gender detection tools were employed to infer gender from the first name (or both first name and surname) as previous research has found it to be an effective way of saving time and resources, particularly in the "study of gender inequalities in scientific publications, citations, grant allocations, salaries, and career advancement processes" [43]. P. Sebo, based on [44], explains that "Gender detection tools (i.e., name-to-gender inference services) have three main advantages. They are fast, cost-effective, and can be applied retroactively to large datasets.".

This research utilizes the global group of Fab Academy graduates (NG=1,433) and categorizes them by region. Genderize.io application online [45] (Name-to Gender Classification) [46], was used to determine the gender distribution, leveraging its proven effectiveness in previous inference research [47].

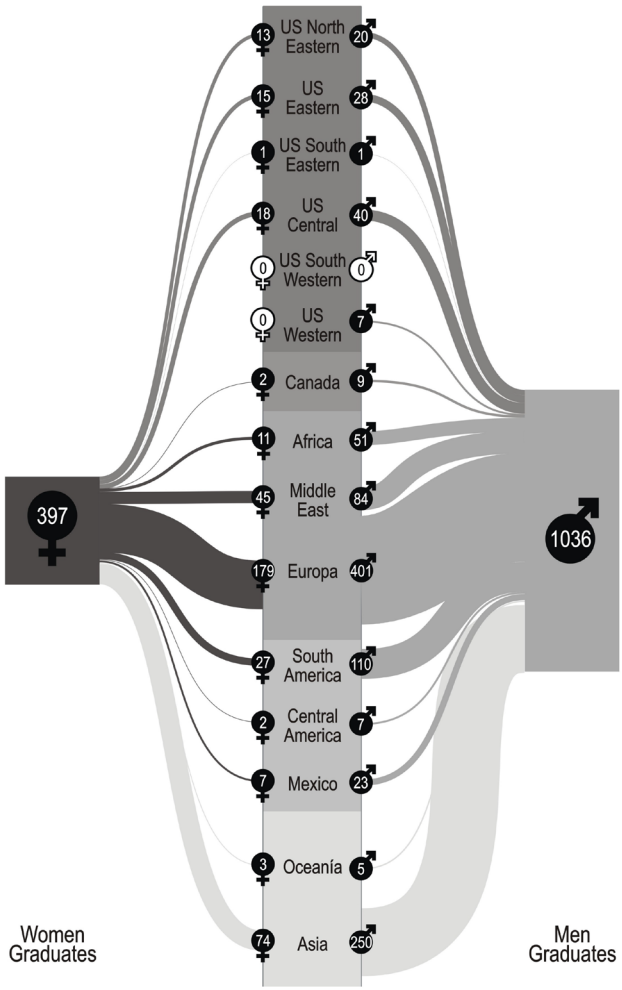

Fig. 6. Number of Women (NWG) and Men Graduates distribution by IEEE Regions 1 to 10.

III. Results

For the first time, we are presenting the results of an analysis on the women graduates in North America in the content of the Fab Lab-based learning methodology. We have extracted data from Fab Labs and analyzed the Number of Fab Labs (NFL), Number of Fab Labs with Fab Academy Nodes (NFA), and the Number of Fab Academy Nodes with women graduates (NFAWG) in Section A.

Interpreting the Fab Academy Graduates data, we analyze in Sections B and C, the Number of Graduates (NG), and the Number of Women Graduates (NWG).

A. Fab Labs analysis

According to Fab Foundation, there were (NFL=277) Fab Labs in Regions 1 to 6 and (NFL=42) in Region 7. In this section, we will analyze the number of Fab Labs Nodes (NFA) in the US Regions and the US States in the Fab Academy program.

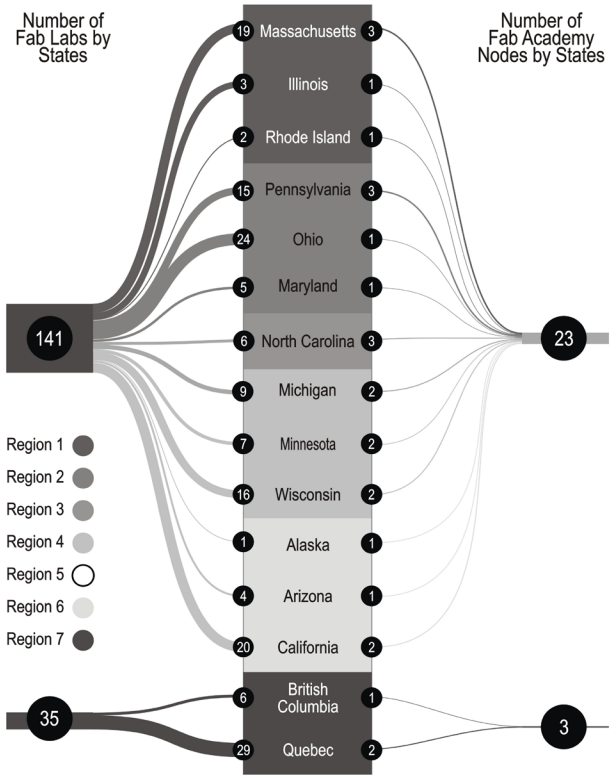

Fig. 7. Number of Fab Labs (NFL) and Fab Academy Nodes (NFA) by US States (Regions 1 to 6) and Provinces of Canada (Region 7).

a) Fab Labs by Region: Region 1 US Northeastern represents 21% (NFL=58) of the total number of Fab Labs in North America. Region 4 US Central has the most Fab Academy Nodes (NFA=9).

b) We found that the regions with the most Fab Labs are the IEEE Regions with the fewest Fab Academy Nodes. Not all IEEE Regions in North America have Fab Academy Nodes, thus no graduates. Based on Figure 2, we found that 136 Fab Labs were excluded from the screening. This analysis revealed that Region 5 US Southwestern does not take part in the Fab Academy Program. Out of its 37 Fab Labs, none are a part of the Fab Academy. Additionally, in Canada, only two Provinces

have Fab Academy Nodes: British Columbia in the west and Quebec in the east.

c) Fab Labs by States: According to Fab Foundation records [37], the NFL=277 Fab Labs are distributed in 41 US States. The US State with the most Fab Labs (NFL=24) and that has at least one Fab Academy Node is Ohio State in Region 2 US Eastern. However, Ohio has only (NFA=1) Fab Academy Node. Region 5 includes US States without Fab Academy Nodes (NFA=0): Texas, Lousiana, Oklahoma, Kansas, Colorado, Idaho, Missouri, Arkansas, Wyoming, and Western Nevada and South Dakota. We counted three US States that have the largest number of Fab Academy Nodes (NFA=3): Massachusetts, MA (Region 1), Pennsylvania, PA (Region 2) and North Carolina, NC (Region 3).

B. *Women Graduates (NWG)*

In Figure 8, Regions 1 to 6 show NWG=47 graduates, and Region 7 NWG=2. For Regions 1 to 6, the first graduates were NG=5, two women and one man. In 2011, the percentage difference was 57% for women (NWG=4) and 43% for men (N=43). This high percentage of women also happened 2015 with 60% women (NWG=9) and 30% men (N=6), and 2018 with 56% women (NWG=5) and 44% men (N=4).

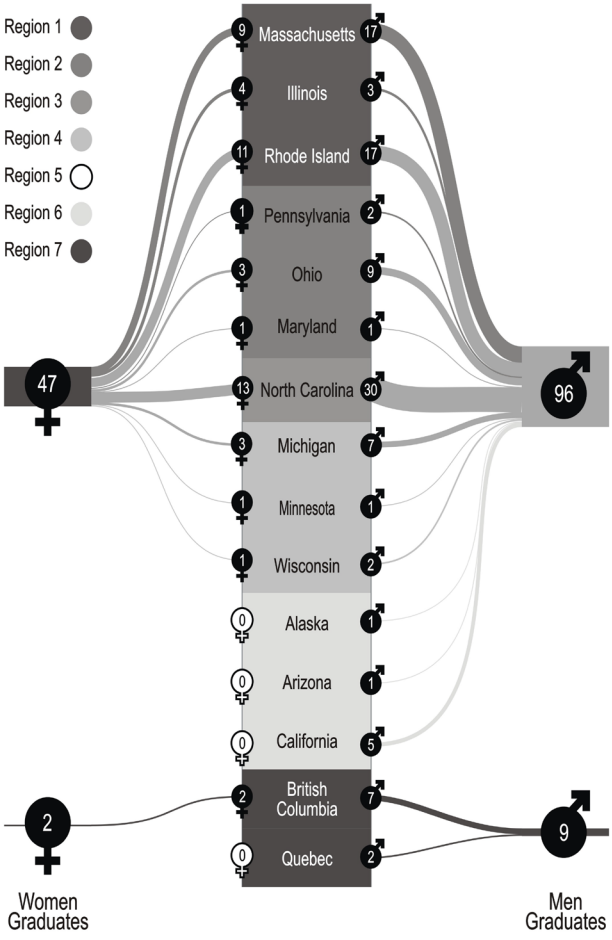

Fig. 8. Number of Fab Academy Graduates by women/men graduates from US States / Provinces (Canada) for the IEEE Regions 1 to 7.

The other years, the proportion has been equivalent, with the exception of 2016 with 17% women (NWG =3) and 83% men (N=15); and 2021 with 22% women (NWG =4) and 78% men (N=14).

Region 7 (Canada) saw its first graduate in 2015, with only one graduate. In 2016, only one woman graduated. The second woman graduated in 2019, along with three men.

a) Women Graduates by Region: Region 4 US Central is the region with the highest number of Fab Academy Nodes (NFA=9) and has the highest number of women graduates (NWG=18).

Regions 1 through 6 have an average of 67% men graduates (N=96) and 33% women graduates (N=47). Three regions have above average percentages, Region 1 (33%), Region 2 (35%) and Region 3 (50%).

b) Women Graduates by States: Figure 7 shows that MA, PA and NC are the US States with the highest number of Fab Academy Nodes each (NFA=3). However, PA had only NG=3 graduates, while MA (NG=26) and NC (NG=43). Rhode Island (RI), the smallest US State in terms of surface area, and North Carolina (NC) have the highest number of women graduates: RI (NWG=11) and NC (NWG=13).

C. *Analysis of Fab Lab women graduates*

Fab Academy Nodes are the specialized infrastructure of the Fab Academy program. With a total of 23 Fab Academy Nodes, 47 women have graduated from these case studies.

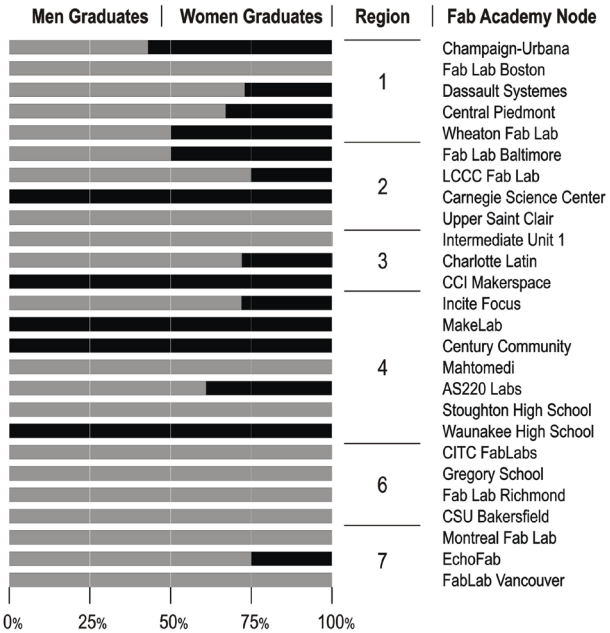

Fig. 9. Men and Women Graduates distribution by Fab Academy Nodes for the IEEE Regions 1 to 7.

Eleven out of 23 Fab Labs Nodes do not report women graduates from their laboratories (NWG=0). There are located in seven US States: MA (Region 1), PA (Region 2), MN (Region 4), WI (Region 4), AK (Region 6), AZ (Region 6), CA (Region

6), had no women graduates (full gray color, Fig. 9). This indicates that none of the Fab Academy Nodes in Region 6 US Western had women graduates. Five Fab Academy Nodes had only women graduates and are located in PA, NC, MI, MN, WI. Three of those Fab Academy Nodes are in Region 4 US Central, a region that contributes seven Nodes to the total. It should be noted that all of the Fab Academy Nodes that had only women graduates had only one graduate in their Fab Academy programs.

IV. Discussion

The Fab Academy ecosystem [29] is open and shared, and this includes the selection process for infrastructure [28]. Graduates [9], number of labs, location and management organization chart [38], curriculum structure, handbooks for instructors [30] and students [29], Fab Academy regulations to certified graduates [31], and Fab Lab Nodes [39], etc. This open access allowed us to identify the instances and data behind the process. The absence of statistical data on gender since the creation of the Fab Academy in 2008 allowed us to reconstruct this history from the Fab Foundation's open data. The positive results in different regions coincide with qualitative research and manifestos on the nature of Fab Labs and its Fab Academy program.

The Fab Lab-based Learning culture has been substantiated in different contexts. This research adds statistics to substantiate the effect of the methodology. The main aspect of discussion, therefore, is the absence of the methodology in more learning contexts.

The Fab Foundation's open ecosystem proposes a learning culture, but does not interfere in the administrative system of the institutions that choose to include the methodology in their Fab Labs. The first indicator is the difference in the number of Fab Academy Nodes (NFA) versus the number of Fab Labs (NFL) in the same city, state, province or region (Fig. 3). The qualification and requirement system is demanding, but it also requires a culture to be installed in the people who form, will form and manage the ecosystem. For this reason, the number of graduates in general is variable.

If we insert the North American Fab Academy Nodes in time, we will also see that most of them are not active or their instructors and mentors have migrated to other labs. We infer that this is not a problem of the methodology, but of the lack of institutionalization where a Fab Academy Node is inserted. When the initiatives grow in an individualized way and are not part of the curricular politic, the challenges to maintain an initiative in force diminish, until they disappear. Therefore, it is expected that in the future we will identify the qualitative aspect as a complement for its academic sustainability.

It is important to note that the ecosystem empowers people and not laboratories. It has demanding requirements in infrastructure, but the infrastructure changes, renews and evolves, therefore it does not have a unique value like people (instructors, mentors and gurus). This distinction may not be important for institutions, but it is necessary to investigate and analyze it from a qualitative perspective. This situation is not particular to the methodology, but to the educational system faced by any disruptive implementation, which is emerging as a topic for future discussion.

We consider that Fab Lab-based learning is not a methodology created to bridge the gender gap, but it is a form of learning that has dimensions that have been independently successful, and at the same time motivating for women in the STEM context [7], [13], [14], with project-focused features using emerging technologies from different disciplines in which different people work [15]. Particularly, because it grew in a historical context where computing was feminized [11] led by women. Consequently, in this research we present evidence of the effect of apprenticeship in the Fab Academy context through global and regional statistics, with a pending step in the evaluation of the contexts hosting the initiatives.

This research highlights contexts where a deeper and more detailed study is required with important challenges [5, 6], in which we alert needs and identify new sustainability strategies.

V. Conclusions

Gender assignment was not self-determined, and ethical problems arise when simplifying the concept of gender to just men and women. To address this issue [4], we utilized filters on OSNs [41], SNSs [42], and gender inference tools for our research [42, 44]. This allowed us to compare gender differences in 10 regions of the world, with a specific focus on IEEE regions 1 to 7. Our research addresses the gap in raw data in institutional reports, which typically rely only on samples [5]. In contrast, our study encompasses the universe of Fab Academy graduates worldwide (NG=1,433). Our analysis is centered on a learning methodology that operates within a globalized framework while being rooted in a local institution, enabling us to effectively address the third issue [6] without being influenced by the political or managerial circumstances of external organizations.

This is an important step toward understanding gender variations in large datasets. We hope that this research will serve as a starting point for more in-depth qualitative studies and lead to new findings in other contexts of gender.

In this research, we analyzed the total number of Fab Academy graduating classes between 2009 and 2023 in the context of IEEE Regions 1 to 6 (United States) and Region 2 (Canada) and compared their results with regions 8, 9, and 10 (Fig. 1). In our regional analysis, we used an exclusion flow (Fig. 2) and identified NFL=277 Fab Labs in the United States and NFL=42 in Canada, distributed in US Region 1 (NFL=58), US Region 2 (NFL=44), US Region 3 (NFL=57), US Region 4 (NFL=40), US Region 5 (NFL=37), US Region 6 (NFL=41), and Canada Region 7 (NFL=42). Out of a total of NFL=319, we identified those that achieved Fab Academy Nodes status (Fig. 3) including Fab Labs in the United States (NFA=23), and Canada (NFA=3).

The Fab Academy Nodes are key indicators of our graduates. In the map of North America (Fig. 4), we can see regions and states that are not included in our analysis. Our initial analysis focused on regions. We first identified the Fab Academy Nodes, and then analyzed the number of graduates in IEEE Regions 1-10 and their percentage of graduates in the global ecosystem (Fig. 5). We also analyze the number of graduates by gender (Fig. 6). Our second analysis delves into the number of Fab

Academy Nodes by sub-regions, specifically looking at the involvement of 13 US States and 2 provinces in Canada out of the 10 (Fig. 7). This allows for a more detailed examination of the gender gap in a specific learning context (Fig. 8). Finally, our third analysis examines the connection between the Fab Academy Node and the gender gap of its graduates (Fig. 9).

The total number of women graduates in Regions 1-10 is (NWG=397). Region 8 (Africa, Europe, Middle East) boasts the highest percentage, with (NWG=2350 women graduates accounting for 59% of the total. This is followed by IEEE Region 10 (Asia, Oceania) with (NWG=77) women graduates, representing 19%, and IEEE Regions 1-6 (USA) with (NWG=47) women graduates, making up 12%. The regions with the fewest women graduates are IEEE Region 9 (Latin America) with 36, representing 9%, and IEEE Region 7 (Canada) with 2, accounting for 1%.

When looking at the world's total number of women graduates (NWG=397), Region 4 contributes 5%, a higher percentage than any other country in Region 9. Europe is the subregion with the most women graduates, with 179 representing 45% of the total, followed by Asia with 74 (19%) and the Middle East with 45 (11%). In the regions corresponding to the United States, IEEE Region 4 (US Central) has the highest contribution of women graduates with 18 (5%), followed by Region 2 (US Eastern) with 15 (4%) and Region 1 (US North Eastern) with 13 (3%).

The total number of women graduates in the Fab Academy of IEEE Regions from the United States is 33%, which is the highest among all regions. Region 7 has 18% women graduates, Region 8 has 30%, Region 9 has 20%, and Region 10 has 23%. Apart from Canada, the Northern Hemisphere (IEEE Regions 1 to 8) maintains a higher percentage of women graduates compared to the Southern Hemisphere (IEEE Regions 9 and 10). However, at the sub-region level, Region 8, which includes the Middle East, is still considered the sub-region with the highest percentage of women graduates (35%).

Through Sankey diagrams and a map, we present visual comparisons to highlight precise distinctions that support the analyzed statistics.

We discovered that there are no initiatives in the central regions of Canada. The Fab Academies are in opposite Provinces of the country, with one in British Columbia to the west and the other in Quebec to the east (See Fig. 4). On the map (Fig. 4), we visualize the absence of initiatives in the central region of the United States and some parts of the southeastern region. However, the Eastern, Northeastern and Western areas do have Fab Academy Nodes.

The Fab Academy is a challenging program that requires a significant time commitment and the development of advanced skills. As a result, the graduation challenge is quite demanding. In the future, it would be interesting to measure the drop-out rate of students and compare it to the percentage of students who successfully complete the program. It is expected that the difference between these two percentages will be minimal.

Our research provides quantitative evidence to support previous qualitative findings demonstrating the positive impact of implementing Fab Labs and it Fab-Lab based learning. This includes identifying challenges that need to be explored further in future research. We hope this research can be used as a reference for implementation efforts in areas where there is still a significant gap. Our goal is to inspire a transformative ecosystem, not just to close a gap, but to address people's issues and needs. Where it does not differentiate based on gender, but embraces diversity, and the interest in expanding the participation of all to build a better and sustainable world.

ACKNOWLEDGMENT

We would like to thank to ProteinLab Universidad Tecnológica Metropolitana (UTEM), Innova UTEM and ANID InES Género INGE210029 (UTEM). This research has been supported by the Dirección de Investigación of the Universidad Peruana de Ciencias Aplicadas (UPC) with UPC-EXPOST-2024-2.

REFERENCES

[1] I. M. Montingelli, A. Malucelli, S. Reinehr, and C. N. Silla, “Bringing More Girls to STEM: Initiatives within the Frontiers in Education Conference,” in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023, pp. 1–8.

[2] World Economic Forum, “World Economic Forum, Global Gender Gap Report,” 2023. .

[3] P. Meiksins, C. Garcia, N. Huggins, M. Menon, and O. Ryan, “Women in Engineering: A Review of the 2022 Literature,” *SWE Mag. Soc. Women Eng.*, vol. 69, no. 2, pp. 6–46, 2023.

[4] M. F. Roy *et al.*, *A Global Approach to the Gender Gap in Mathematical, Computing, and Natural Sciences: How to Measure It, How to Reduce It?* Zenodo, 2020.

[5] G. Vargas-Solar, “Intersectional Study of the Gender Gap in STEM through the Identification of Missing Datasets about Women: A Multisided Problem,” *Appl. Sci.*, vol. 12, no. 12, p. 5813, 2022.

[6] D. Reeping and N. Rashedi, “Work in Progess: A Decade-Spanning Longitudinal Study on the Curricular Complexity of Engineering Programs,” in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023, pp. 1–5.

[7] Y. Pourrat and A. Beraud, “Gender in engineering education,” in *2014 IEEE Global Engineering Education Conference (EDUCON)*, 2014, pp. 158–163.

[8] European Institute for Gender Equality, “Integrating gender equality into academia and research organisations,” *Anal. Pap. Publ. Off.*, 2016.

[9] Fab Academy, “Graduates,” Fab Academy, 2023. [Online]. Available: https://fabacademy.org/students/alumni-list.html. [Accessed: 15-Apr-2024]

[10] IEEE Xplore Digital Library https://ieeexplore.ieee.org/Xplore/home.jsp [Accessed: 2-Mar-2024]

[11] T. Misa, “Dynamics of gender bias in computing,” *Commun. ACM*, vol. 64, no. 6, pp. 76–83, 2021. https://doi.org/10.1145/3417517

[12] J. Vig, “Why So Few Women in IEEE, and What Can IEEE and WIE Do About It? [Letter to the Editor],” *IEEE Women Eng. Mag.*, vol. 15, no. 1, pp. 5–5, 2021. doi: 10.1109/MWIE.2021.3062919

[13] B. H. Westh, N. Inie, L. Barkhuus, and C. Brabrand, “Gender Differences in the Group Dynamics of Smaller CS1 Project Groups,” in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023, pp. 1–9. doi: 10.1109/FIE58773.2023.10343369

[14] C. R. Bego and J. C. Nwokeji, “Diversity and inclusion in engineering and computing: A scoping review of recent FIE papers,” in *2021 IEEE Frontiers in Education Conference (FIE)*, 2021, pp. 1–9.

[15] N. Azhani, I. Veza, and I. Ghazali, “Women in Engineering Education: Five Strategies to Promote Women in Engineering Education,” *Eng. Sci. Lett.*, vol. 2, no. 2, pp. 53–58, 2023.

[16] A. Tarchini, “Connecting the dots: MATLAB® and Simulink® help engineering education to take advantage of new teaching agents,” in *IEEE Global Engineering Education Conference (EDUCON)*, 2014.

[17] E. van Holm, “What are Makerspaces, Hackerspaces, and Fab Labs?,” *SSRN*, 2014.

[18] S. Mersand, “The State of Makerspace Research: a Review of the Literature,” *TechTrends*, vol. 65, pp. 174–186, 2021.

[19] S. A. Soomro, H. Casakin, and V. Nanjappan, “Makerspaces Fostering Creativity: A Systematic Literature Review,” *J. Sci. Educ. Technol.*, vol. 32, pp. 530–548, 2023.

[20] P. Blikstein, J. Silveira, and H. T. Akiba, “The Effect of Highly Scaffolded Versus General Instruction on Students ’ Exploratory Behavior and Arousal,” *Technol. Knowl. Learn.*, vol. 22, no. 1, pp. 105–128, 2017.

[21] C. Kaar and C. Stary, “Structuring Academic Education in Makerspaces: Consolidated Findings from the Field,” in *2019 IEEE Global Engineering Education Conference (EDUCON)*, 2019, pp. 920–927.

[22] R. Brown and A. Antink-Meyer, “Makerspaces in Informal Settings,” *Educ. Technol.*, vol. 57, no. 2, pp. 75–77, 2017.

[23] P. Herrera, V. Caycho, and M. Valenzuela, "Women in the Fab Lab ecosystem (2008-2021). From Fab Academy to the Fab Lab Research Conferences," Proceedings of the Fab 16 Research Papers Stream, Montreal, Canada, Aug. 2021, pp. 271-280. doi: 10.5281/zenodo.5169858.

[24] CBA MIT, “Students,” 2008. [Online]. Available: https://fab.cba.mit.edu/classes/863.08/people/ . [Accessed: 15-May-2024].

[25] CBA MIT, “Students in Fall,” 2005. [Online]. Available: https://fab.cba.mit.edu/classes/863.05/people/ . [Accessed: 15-May-2024].

[26] MIT, “MAS 863 Students.” [Online]. Available: http://www.media.mit.edu/physics/pedagogy/fab/fab98/fall1998.htm. [Accessed: 15-May-2024].

[27] J. Ylioja, G. Georgiev, I. Sánchez, and J. Riekki, “Academic Recognition of Fab Academy,” in *FabLearn Europe 2019 Conference (FabLearn Europe ’19).*, 2019, pp. 1–7.

[28] Fab Foundation, “Getting Started with Fab Labs.” [Online]. Available: https://fabfoundation.org/getting-started/. [Accessed: 15-May-2024].

[29] Fab Foundation, “Fab Academy Handbook 2020.” .

[30] Fab Foundation, “Instructor Handbook.” [Online]. Available: https://academany.fabcloud.io/fabacademy/instructors-handbook/. [Accessed: 15-May-2024].

[31] Fab Foundation, “No Fab Academy 2024 Assignments and Assessment.” [Online]. Available: https://academany.fabcloud.io/fabacademy/instructors-handbook/. [Accessed: 15-May-2024].

[32] P. C. Herrera, C. Dreifuss-Serrano, M. Valenzuela-Zubiaur and V. Caycho, "Fab Lab-based learning: an environment to promote Women and Leadership in Engineering Education," 2022 IEEE Global Engineering Education Conference (EDUCON), Tunis, Tunisia, 2022, pp. 1336-1345, doi: 10.1109/EDUCON52537.2022.9766775.

[33] P. C. Herrera, M. Valenzuela-Zubiaur, V. Caycho and C. Dreifuss-Serrano, "Beyond Class Activities to Involve Women. Fab Lab-Based Learning in Latin America," 2024 IEEE World Engineering Education Conference (EDUNINE), Guatemala City, Guatemala, 2024, pp. 1-6, doi: 10.1109/EDUNINE60625.2024.10500657.

[34] K. Beddoes, “Feminist methodologies and engineering education esearch,” *Eur. J. Eng. Educ.*, vol. 38, no. 1, pp. 1–24, 2013.

[35] A. Mazzurco, E. Crossin, S. Chandrasekaran, S. Daniel, and G. R. P. Sadewo, “Empirical research studies of practicing engineers: a mapping review of journal articles 2000–2018,” *Eur. J. Eng. Educ.*, pp. 1–24, 2020.

[36] M. Berge, E. Silfver, and A. Danielsson, “In search of the new engineer: gender, age, and social class in information about engineering education,” *Eur. J. Eng. Educ.*, vol. 44, no. 5, pp. 650–665, 2019.

[37] J. Eckhardt, C. Kaletka, B. Pelka, E. Unterfrauner, C. Voigt, and M. Zirngiebl, “Gender in the making: An empirical approach to understand gender relations in the maker movement,” *Int. J. Hum. Comput. Stud.*, vol. 145, 2021.

[38] Fab Lab Foundation, “Fab Labs around the globe,” 2024. [Online]. Available: https://fablabs.io/. [Accessed: 23-Mar-2024].

[39] Fab Academy, “Nodes,” *Fab Academy*, 2024. [Online]. Available: https://fabacademy.org/nodes/list2022.html . [Accessed: 15-Apr-2024].

[40] Fab Academy, "Student profile sample," *Chenxin Yang Fab Academy Journey*, 2024. [Online]. Available https://fabacademy.org/2024/labs/chaihuo/students/chenxin-yang/. [Accessed: 22-July-2024].

[41] C. Tang, K. Ross, N. Saxena, and R. Chen, "What’s in a Name: A Study of Names, Gender Inference, and Gender Behavior in Facebook" in *Database Systems for Adanced Applications. DASFAA 2011. Lecture Notes in Computer Science*, J. Xu, G. Yu, S. Zhou, R. Unland, Eds. Berlin, Heidelberg: Springer, 2011, vol 6637, pp. 344-356. https://doi.org/10.1007/978-3-642-20244-5_33

[42] U. Oberst, V. Renau, A. Chamarro, and X. Carbonell, " Gender stereotypes in Facebook profiles," *Computers in Human Behavior*, vol. 60, no. C, pp. 559-564, 2016. https://doi.org/10.1016/j.chb.2016.02.0

[43] P. Sebo, " Performance of gender detection tools: a comparative study of name-to-gender inference services," *J Med Libr Assoc*., vol.109, no. 3, pp. 414-421, 2021. doi: 10.5195/jmla.2021.1185

[44] L. Santamaría, and H. Mihaljević, " Comparison and benchmark of name-to-gender inference services," *PeerJ Comput Sci*., 4, e156, 2018. https://doi.org/10.7717/peerj-cs.156

[45] Demografix ApS, "Genderize.io," *Check the Gender of a Name*, 2024. [Online]. Available: https://genderize.io/. [Accessed: 15-Apr-2024].

[46] Demografix ApS, "The Technology Behind Our Services," *Name-to-Gender Classification*, 2024. [Online]. Avalilable: https://genderize.io/features/gender-name. [Accessed: 2-Aug-2024]

[47] P. Sebo, " Using genderize.io to infer the gender of first names: how to improve the accuracy of the inference," J Med Libr Assoc., vol.109, no. 4, pp. 609-612, 2021. https://doi.org/10.5195%2Fjmla.2021.1252