Analyzing implicit gender bias in Optics and Photonics at the predoctoral stage in Spain

Analizando el sesgo implícito de género en Óptica y Fotónica en la etapa predoctoral en España

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ABSTRACT:

Gender biases play a very significant role in areas related to science, technology, engineering, and mathematics (STEM). The association of gender with certain attributes, behaviors or professions leads to a lower proportion of women in STEM. In the field of Optics and Photonics, we can identify a gender disparity between technical or bio-clinical approaches within the same area when examining the authorship of the defended thesis. In this work, we quantify the impact of implicit gender bias in the Ph.D. programs related to Optics and Photonics in Spain. Here we present an exhaustive study about the UNESCO descriptors of the theses defended within 2015-2020 through the open-access repository TESEO, where all the doctoral theses of Spanish universities are compiled. The doctorate program of each thesis is considered and classified into a technical or bio-clinical category. With this classification, we quantify the number of male and female authors within each category, and the results show up a clear unbalance in most of the evaluated descriptors: men are more likely to choose technical doctorate programs, while women are mostly present in clinical or biological programs. This difference is seen even in descriptors where both genders are equally represented. On one side, women's underrepresentation is higher in "Physics", "Astronomy and Astrophysics", "Earth and Space Sciences", and "Technological Sciences". Oppositely, the areas of "Chemistry", "Life Sciences", and "Medical Sciences" show a greater gender-balanced distribution for most of the descriptors.

Key words: gender bias, gender gap, optics and photonics, Ph.D. theses, women in science

RESUMEN:

Los prejuicios de género desempeñan un papel muy importante en áreas relacionadas con la ciencia, la tecnología, la ingeniería y las matemáticas (STEM). La asociación del género con determinados atributos, comportamientos o profesiones conduce a una menor proporción de mujeres en STEM. En el campo de la Óptica y la Fotónica, podemos identificar una disparidad de género entre enfoques técnicos o bioclínicos dentro de la misma área al examinar la autoría de la tesis defendida. En este trabajo, cuantificamos el impacto del sesgo implícito de género en los programas de doctorado relacionados con la Óptica y Fotónica en España. Aquí presentamos un estudio exhaustivo sobre los descriptores UNESCO de las tesis defendidas en el periodo 2015-2020 a través del repositorio de

acceso abierto TESEO, donde se recopilan todas las tesis doctorales de las universidades españolas. Se considera el programa de doctorado de cada tesis y se clasifica en una categoría técnica o bioclínica. Con esta clasificación, cuantificamos el número de autores y autoras dentro de cada categoría, y los resultados muestran un claro desequilibrio en la mayoría de los descriptores evaluados: los hombres son más propensos a elegir programas de doctorado técnicos, mientras que las mujeres están mayoritariamente presentes en programas clínicos o biológicos. Esta diferencia se observa incluso en los descriptores en los que ambos sexos están representados por igual. Por un lado, la infrarrepresentación femenina es mayor en "Física", "Astronomía y Astrofísica", "Ciencias de la Tierra y del Espacio" y "Ciencias Tecnológicas". Por el contrario, las áreas de "Química", "Ciencias de la Vida" y "Ciencias Médicas" muestran una distribución más equilibrada entre hombres y mujeres en la mayoría de los descriptores.

Palabras clave: sesgo de género, brecha de género, óptica y fotónica, tesis doctorales, mujeres en ciencia

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1. Introduction

The lack of gender diversity in STEM careers is a reality that is increasingly being observed and studied. This unbalance appears at an early age in both girls and boys, including secondary and primary school levels [1]–[8]. For this, one of the strategies adopted has been to study the performance of boys and girls in different subjects, obtaining as a conclusion that girls have better results in general, but the highest gender differences are obtained when looking at high achievers [9]. The situation does not improve either when analyzing the level of attainment of doctoral theses, as the demands and biased expectations for each of the genders hinder the attainment of the highest educational rankings [10], [11]. The production of doctoral theses is a well-established indicator used, for instance, in the evaluation of the scientific quality of researchers and institutions. The analysis of doctoral theses, therefore, allows identifying the hot topics in research and production level, but they can also be an instrument to evaluate the presence of gender bias.

Numerous studies have already shown that the difference in access to the most highly skilled careers systematically translates into difficulty in accessing the best-paid jobs in the labor market, which leads to an established wage inequality between men and women [12]–[15]. Coarse analysis of systematic gender bias in broad areas of science or engineering, such as physics, mathematics, or computer science, is gaining the attention of the academic community [4], [16]–[20]. Few studies have considered the biases present in the subfields of each discipline, even though some of them can cover many different topics, such as the case of Optics and Photonics, currently present in many different research areas [21], [22]. The lack of these fine analyses within the same discipline can be difficult to explore due to the thin boundaries between topics.

Authors have based their work on objective and quantifiable data, such as the doctoral theses defended in Optics and Photonics in Spain [23], [24]. In a preliminary work, we addressed the situation in the field of Optics and Photonics focusing on the theses defended in Spain over a temporal span of five years [25]. By filtering the author's gender and UNESCO descriptors related to Optics and Photonics (79 UNESCO codes in total) in the open-access database TESEO [26], we found a clear gender unbalance in most of the descriptors. This study was a first approach to the problem, but the extracted data used for it allows a more insightful analysis attending other criteria such as in this work, where we carry out this fine analysis of how the gender biases distribute within the same discipline.

The TESEO database provides information about the department and the university where the thesis was carried out, the doctorate program, and the tribunal that judged the thesis defense. We soon realized that the descriptors analyzed in [25] covered a wide range of topics, from purely theoretical to experimental, as well as of a markedly technical or clinical nature. It has been previously reported that women are usually inclined towards fields or topics more related to health or care, while technical areas result more appealing for men [7], [18], [21], [22]. From the data we collected, we present a study in detail within each

descriptor, since each one defines different subareas within Optics and Photonics. The character of the doctoral program to which each of these descriptors was associated is analyzed, to see if the distribution was equitable in terms of gender and the possible gender biases present in them.

2. Database TESEO

TESEO is an open-access database managed by the Spanish Ministry of Universities [26]. It provides information on every defended doctoral thesis in Spain since 1976. The data analyzed in this work is available for every researcher interested in reproducing or broadening our results. Each Ph.D. candidate must upload the Ph.D. thesis details once it is defended and approved, and each university is responsible for verifying the completion of this task. This implies that the present study considers all the theses defended in Spain. For the feasibility of the study, we chose a temporal span of 5 years (2015-2020). However, this is an area of analysis that needs to be constantly updated, so new studies covering time periods as well as broader socio-economic factors are envisaged in the near future.

This database is commonly used to evaluate the quality, novelty and relevance of the different research topics, since theses production is one of the indicators used for such evaluations. This analysis, however, is usually done without taking into account a gender perspective. In our case, we take advantage of the information gathered from TESEO to analyze the reality of gender bias at the earliest stage of scientific careers in Optics and Photonics areas.

The TESEO database provides different information about each one of the theses collected. It includes the name and surname of the Ph.D. candidate, thesis abstract, department and university where the work was carried out, date of the defense, and the members of the tribunal.

Regarding the scientific topic covered in the thesis, the Ph.D. candidate classifies their thesis with a maximum of four keywords, corresponding with the descriptors recognized by the UNESCO nomenclature. For each thesis, we paid attention not only to the UNESCO descriptor but also to the doctorate program and the abstract of the thesis submitted to TESEO. With the combination of these pieces of information, we assigned a character to the thesis: either technological or clinical, if it is related to technical or fundamental practices or related to medical or biological applications, respectively. From these data, we classified the almost 4000 items analyzed in this study. It should be noted that some theses (less than 5%) could be assigned to both categories. To ensure the objectivity of the assignment, several authors of the paper from different areas of expertise analyzed the character of each thesis. This ensured that experts in each of the areas could judge the nature of the theses that could raise doubts and, in any case, they are less than 5% as mentioned before.

3. Results

In this section, we present the classification of the doctoral theses defended in Spain between 2015 and 2020 in terms of the doctorate program they are ascribed to and, in particular, depending on whether they cover a technical or a clinical or biological topic.

As mentioned before, the doctoral theses are classified in TESEO according to UNESCO codes; we analyzed 79 UNESCO descriptors, all of them belonging to Optics and Photonics research topics. The 79 descriptors are grouped into the general categories Astronomy and Astrophysics (code 21), Physics (code 22), Chemistry (code 23), Life Science (code 24), Earth and Space Sciences (code 25), Medical Sciences (code 32) and Technological Sciences (code 33). Here, we present 13 figures showing the results of the analysis for each category; for an easier reading we divided the areas containing more topics (22, 23 and 33) into different figures.

The name of each descriptor together with its UNESCO code can be seen in the Appendix. Of course, there exist more descriptors in each category, but we restrict the study to the areas of Optics and Photonics.

For each UNESCO descriptor, the bar graphs show the percentage and the absolute number of women and men in three categories: the total number of theses compiled within each descriptor (labeled as "Totals"), the theses assigned to clinical or biological doctorate programs (labeled as "Bio") and the theses assigned to technical or fundamental doctorate programs (labeled as "Non-bio"). The vertical axis shows percentages, to illustrate the ratio of men and women in each case.

Figure 1 presents five descriptors of the "Astronomy and Astrophysics" category (code 21) shown in the Table A.1 of the Appendix. There is only one thesis in the clinical or biological doctorate programs in this UNESCO code as expected due to the nature of the research topics within this field. Also, we note that there are only two topics with a gender-balanced distribution, "Position astronomy" and "Astrophysical spectroscopy". In all the other descriptors, an underrepresentation of women is observed. Nevertheless,

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since "Astrophysical spectroscopy" is the descriptor with the larger number of theses, it slightly compensates for the unbalance of the other descriptors when considering the whole area. Still, the overall representation of women is lower than men, in an area targeted mostly as Non-bio.
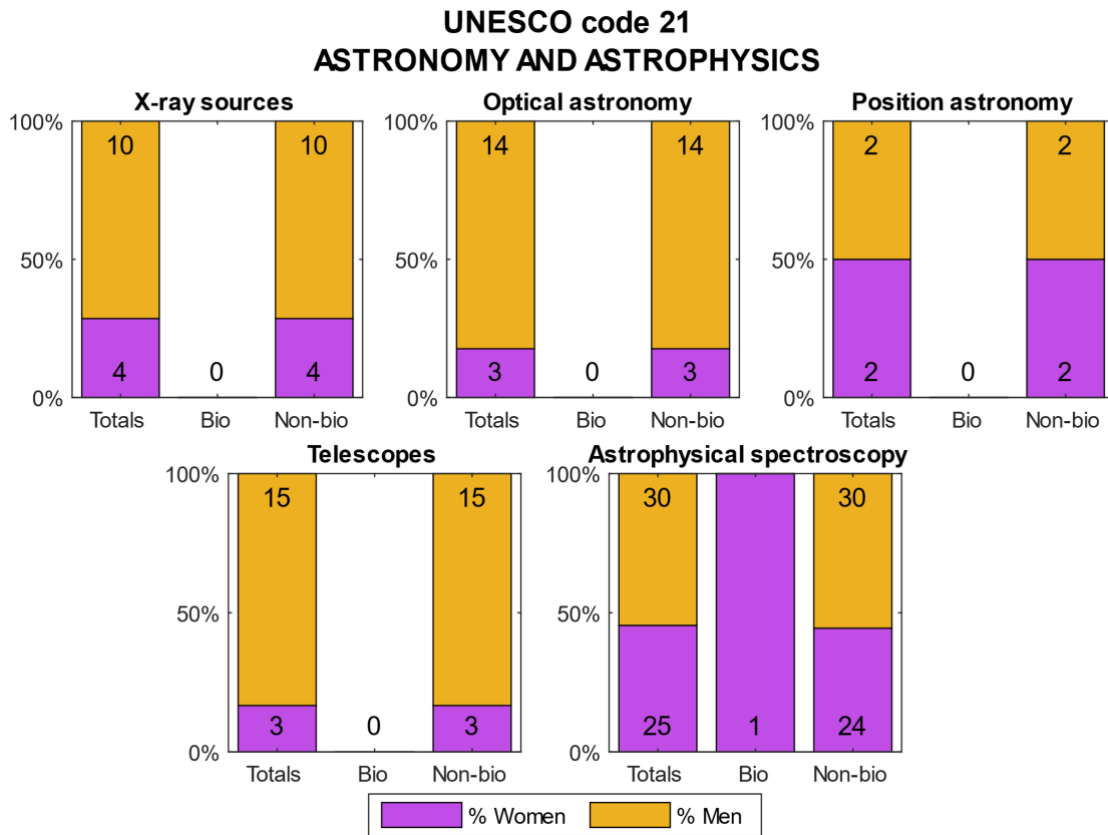

Figure 1. Bar chart, differentiating between women (purple) and men (orange) for five UNESCO codes belonging to category 21 (Astronomy and Astrophysics).

For an easier reading, we divided code 22, which belongs to the "Physics" category and contains the 44 descriptors presented in the Table A.2 of the Appendix, into five figures, from 2 to 6.

Figure 2 illustrates the results of nine UNESCO codes corresponding to the "Physics" area. In this figure, we find some descriptors with a very low number of theses, such as "Laser Molecular Spectroscopy", "Beam handling" or "Beam sources" with 4, 4, and 2 defended theses respectively. In these three descriptors, despite the number being so low to extract a trend, the majority of men can be clearly observed, with most of them in Non-bio topics, and equally divided between women and men in the case of "Beam handling". For the other six descriptors, it can be seen a clear predominance of male presence when analyzing the total number of theses on these topics, except for "X-rays" descriptor where a balanced distribution exists. When looking at the character of the thesis we conclude that in those classified as Bio, the presence of women is bigger in the majority of cases. The only exceptions are "Gamma rays", where in Bio applications are double of men (2 vs. 1) and "Photoelectricity", where all the thesis are classified as Non-bio.
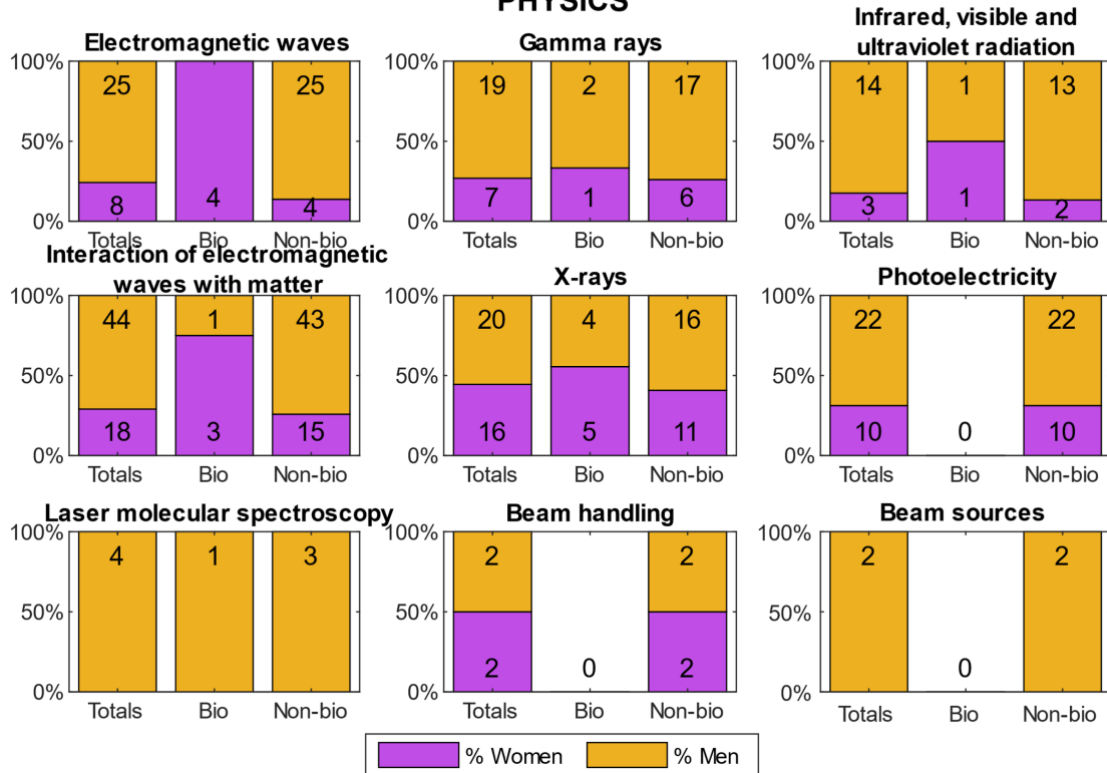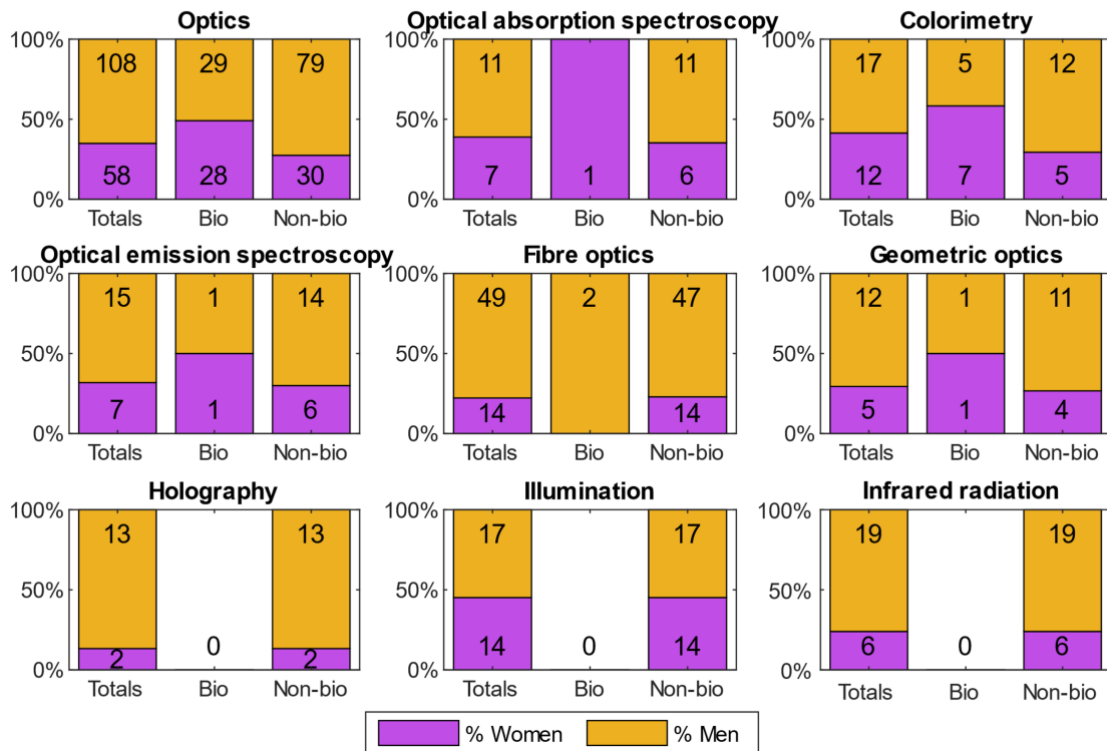
Figure 2. Bar chart, differentiating between women (purple) and men (orange) for nine UNESCO codes belonging to category 22 (Physics).

Figure 3 presents nine more UNESCO descriptors corresponding to the "Physics" area. When looking at the total number of theses, in all descriptors there is always a larger number of theses defended by men than by women. In all categories, a clear male predominance can be observed and a balanced distribution only occurs in "Colorimetry" and "Illumination". When attending the thesis character we observe that in Bio topics the percentage of women is almost always greater than in Non-bio topics.
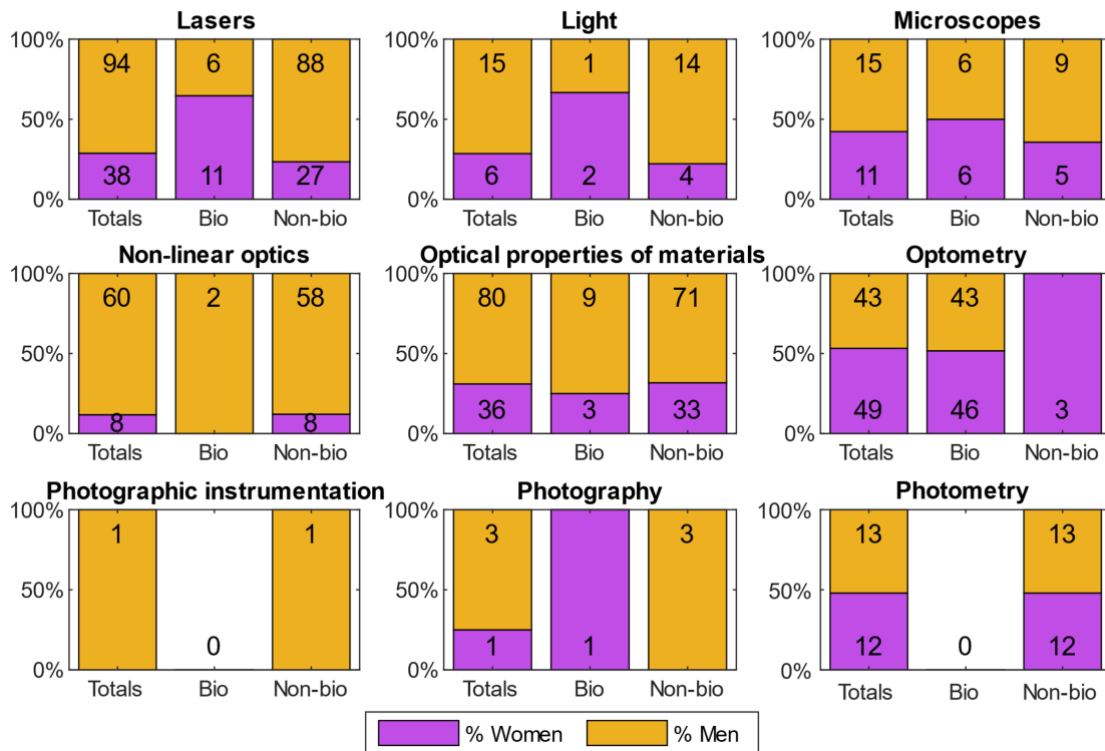
Figure 3. Bar chart, differentiating between women (purple) and men (orange) for nine UNESCO codes belonging to category 22 (Physics).

Figure 4 shows nine more UNESCO descriptors corresponding to the "Physics" area. Evaluating the total number of theses, an unbalanced distribution occurs with a predominance of men in all cases except in "Microscopes", "Optometry", and "Photometry". Additionally, in the cases of "Non-linear optics" and "Photographic instrumentation" the percentage of women does not reach a 20% of the total. On the other hand, the percentage of women is most of the time bigger in the Bio applications than in the Non-bio ones.
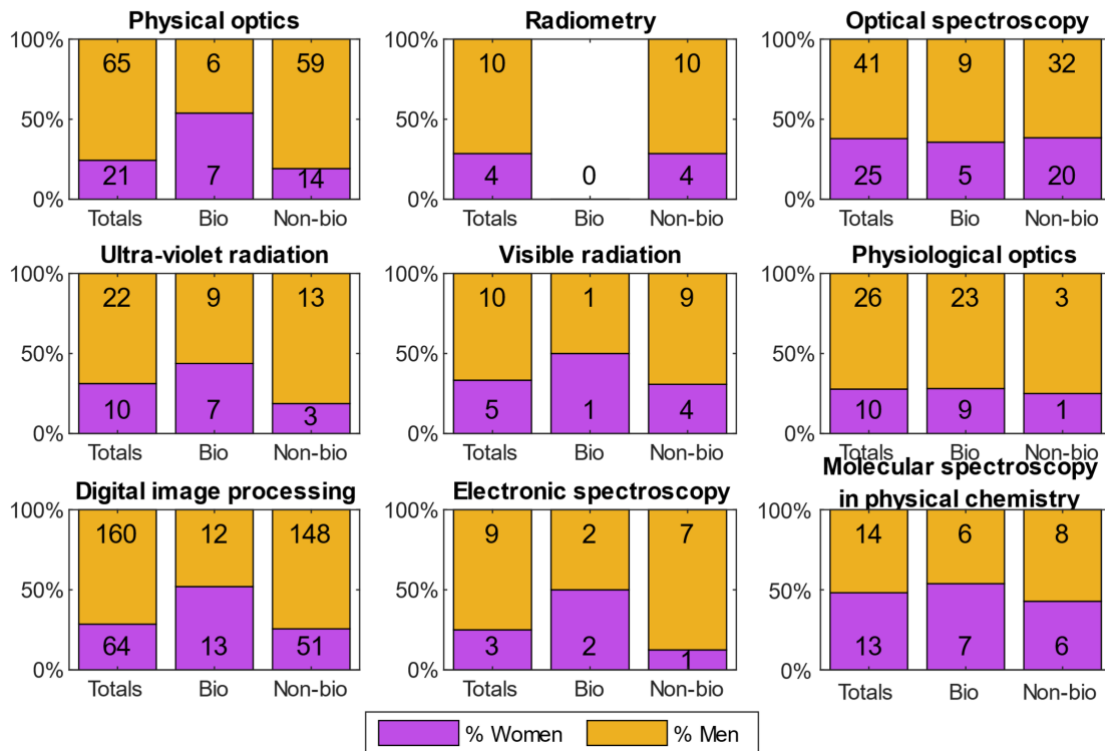
Figure 4. Bar chart, differentiating between women (purple) and men (orange) for nine UNESCO codes belonging to category 22 (Physics).

Figure 5 depicts nine more UNESCO descriptors corresponding to the "Physics" area. Again, there exists a larger percentage of men who defend this type of thesis. A balanced distribution is only found in the "Molecular spectroscopy in physical chemistry" descriptor. Splitting theses into Bio and Non-bio character, in the first one a balanced distribution can be observed in all cases, except for "Optical spectroscopy" and "Physiological optics" descriptors, where there is a greater male presence. However, in the Non-bio theses, the percentage of women is always smaller and in "Physical optics", "Ultra-violet radiation" and "Electronic spectroscopy" it does not even reach a 20% of the total.

UNESCO code 22
PHYSICS

Figure 5. Bar chart, differentiating between women (purple) and men (orange) for nine UNESCO codes belonging to category 22 (Physics).

Figure 6 shows the last eight UNESCO descriptors corresponding to the "Physics" area. In general, the predominant gender was male in most of the descriptors, with the exception of "Luminescence in solids" and "Electromagnetic radiation", where the presence of women was 53.8% and 55% respectively. Moreover, there is also an even distribution between men and women in the descriptor "Photochemistry" and "Interaction of radiation with solids".

Regarding those theses with a biological character, the gender distribution was equitable, with a higher presence of men in two of the descriptors ("Interaction of radiation with solids" and "Metrology"), a higher presence of women in three of them ("Photochemistry", "Luminescence in solids" and "Electromagnetic radiation") and equal representation of genders in another descriptor ("Optical properties of solids").

On the other hand, given the absence of theses associated with Bio Ph.D. programs in "Spectroscopy of solids" and "Photons", 100% of the theses presented in these descriptors are of a technical nature.

On the other hand, all Non-bio theses were conducted in majority by males in all the descriptors with the exception of "Luminescence in solids", in which male representation was almost equitable (48%), and "Electromagnetic radiation", in which gender distribution was equal. In the rest of the descriptors, women are presented in between 23.7% and 41.4% of the analyzed theses.
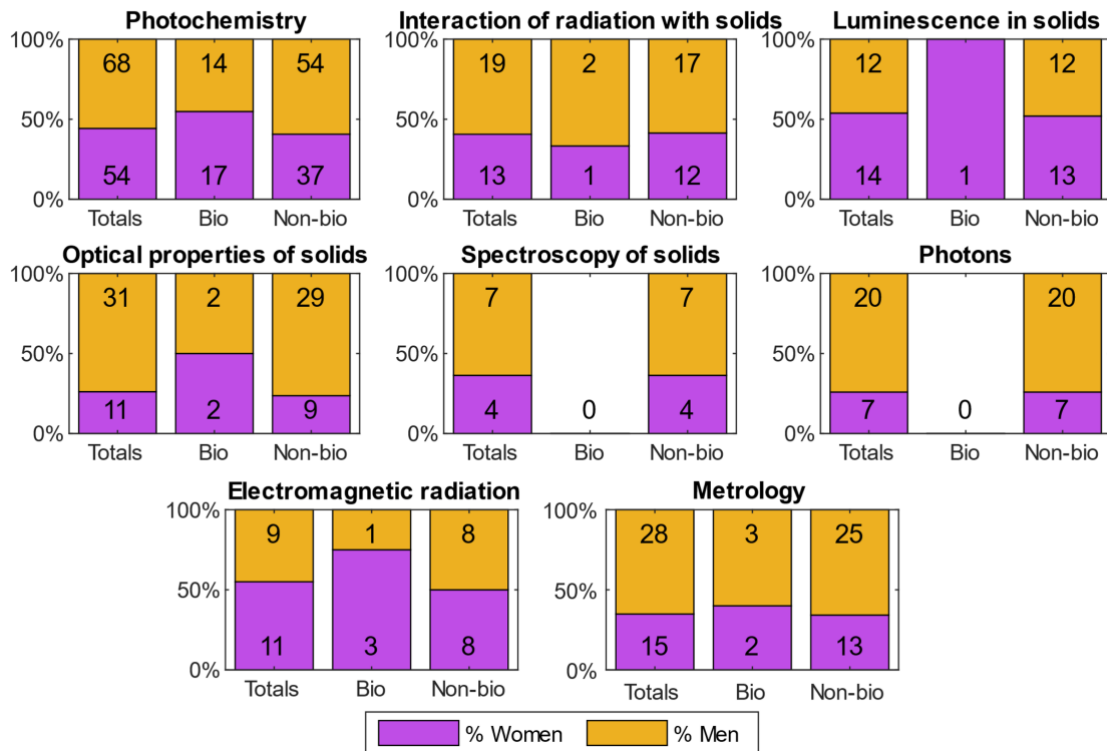
Figure 6. Bar chart, differentiating between women (purple) and men (orange) for eight UNESCO codes belonging to category 22 (Physics).

Next, the 11 descriptors of "Chemistry" category, that can be seen in the Table A.3 of the Appendix, are presented in Figures 7 and 8. The presence of women in the "Chemistry" category is substantially higher. We identify a more balanced distribution of men and women in this category. Indeed, the percentage of female thesis authors is beyond 50% for some descriptors. Curiously, in the chemistry area, where women are not underrepresented at the Ph.D. stage, there is also a greater gender-balanced representation in both Bio and Non-bio Ph.D. programs.
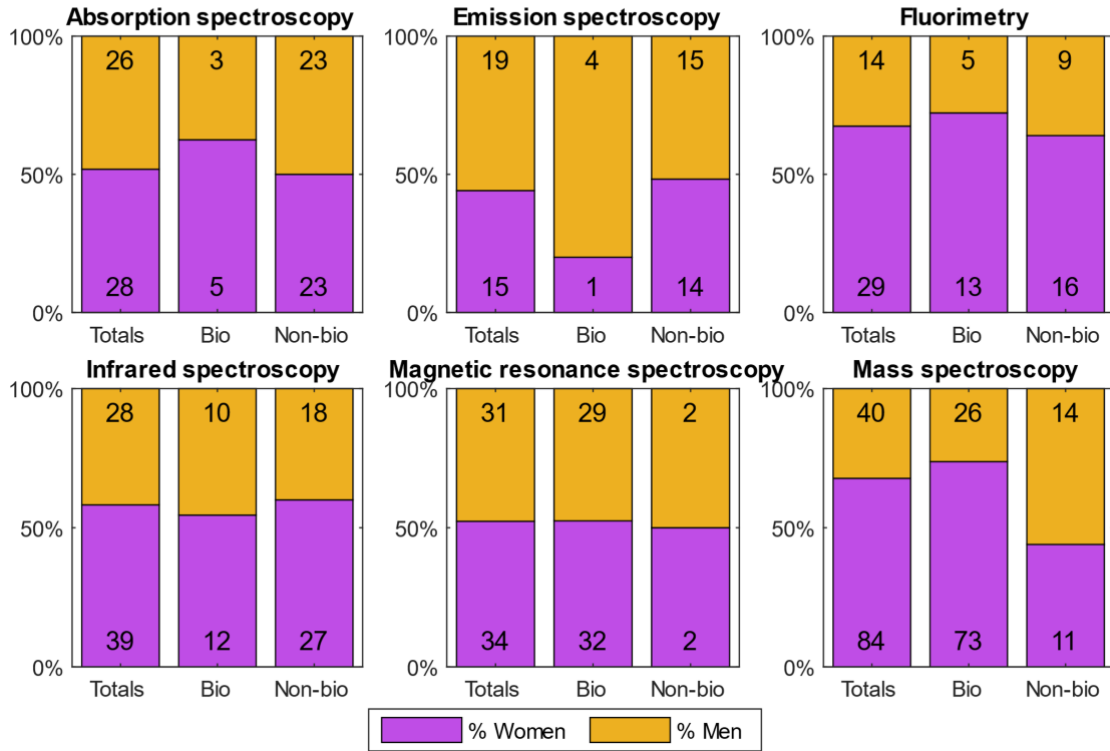
UNESCO code 23
CHEMISTRY

Figure 7. Bar chart, differentiating between women (purple) and men (orange) for six UNESCO codes belonging to category 23 (Chemistry).
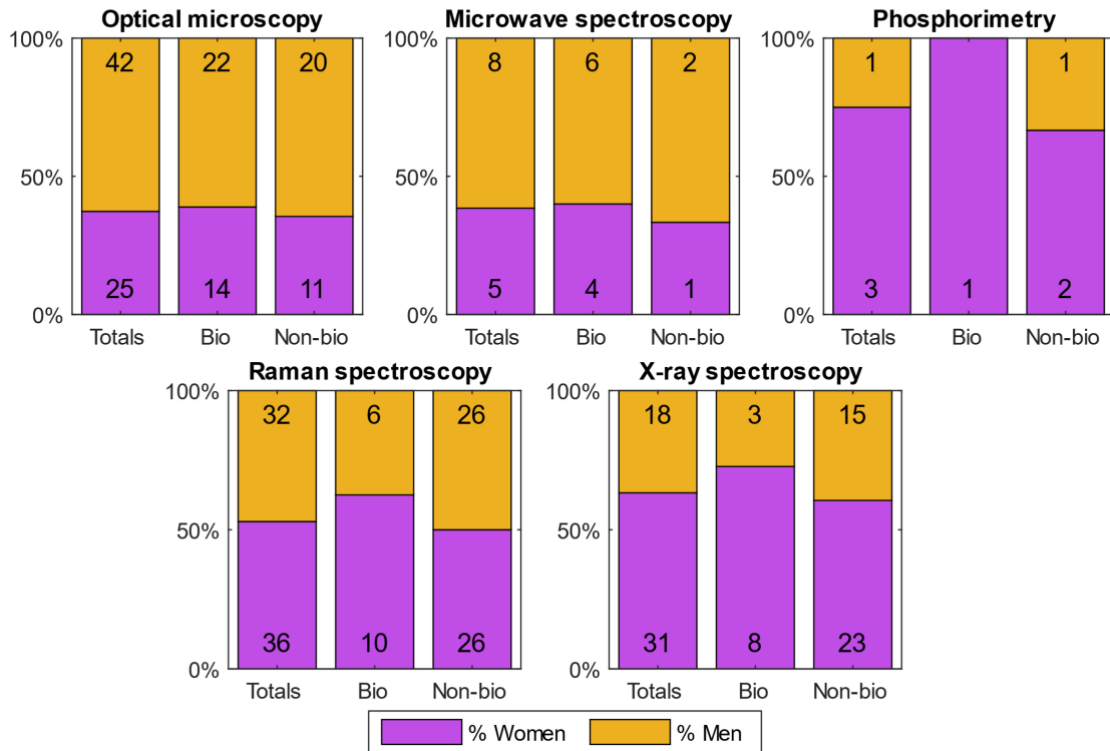
UNESCO code 23
CHEMISTRY

Figure 8. Bar chart, differentiating between women (purple) and men (orange) for five UNESCO codes belonging to category 23 (Chemistry).

Figure 9 illustrates the descriptors of the "Life Sciences" category, shown in the Table A.4 of the Appendix. We can conclude that the theses of a clinical or biological nature are predominant showing an almost balanced distribution of them when splitting by gender.
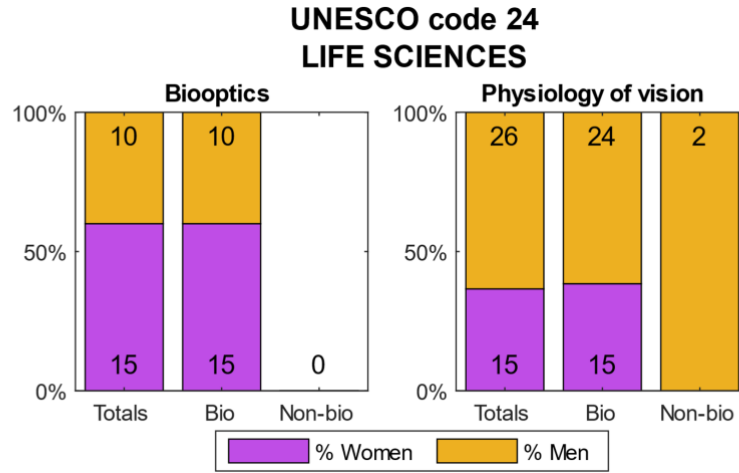

Figure 9. Bar chart, differentiating between women (purple) and men (orange) for two UNESCO codes belonging to category 24 (Life Sciences).

In Figure 10 the three descriptors of "Earth and Space Sciences'' are shown. Those descriptors within their UNESCO code can be checked in the Table A.5 of the Appendix. There is a low number of thesis related to Optics and Photonics in this UNESCO code and the proportion of women is low as well. In addition, the majority of the theses are not related to the biological/clinical category.
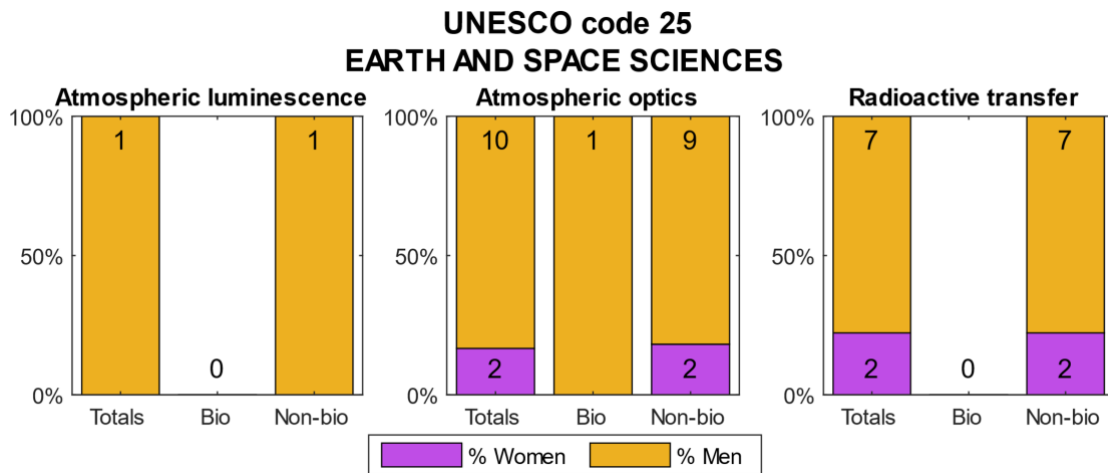

Figure 10. Bar chart, differentiating between women (purple) and men (orange) for three UNESCO codes belonging to category 25 (Earth and Space Sciences).

Continuing with the "Medical Sciences" category, its three descriptors are shown in the Table A.6 of the Appendix and they are depicted in Figure 11. In this UNESCO code, the gender distribution is approximately balanced for all descriptors and there are only a few theses related to technical or fundamental applications.
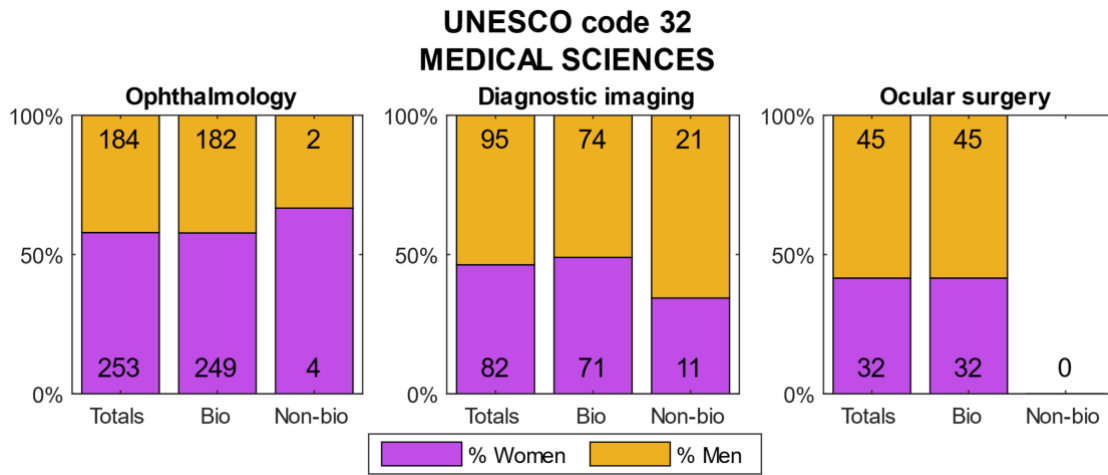
UNESCO code 32
MEDICAL SCIENCES

Figure 11. Bar chart, differentiating between women (purple) and men (orange) for three UNESCO codes belonging to category 32 (Medical Sciences).

Finally, in Figures 12 and 13 we show the data corresponding to UNESCO code 33 labeled as "Technological Sciences", whose descriptors are presented in the Table A.7 of the Appendix.

In all descriptors of "Technological Sciences", we can observe that theses presented by men predominate over those defended by women, with a balanced distribution only in "X-ray devices". Particularly dramatic are the cases of "Machine vision" and "Electro-optical devices" displayed in Figure 12; and "Lenses", "Scientific apparatus" and "Fibre optics communications" presented in Figure 13, showing a percentage of women below 20% of total. This is already a clear indicator that there exists a bias in the areas related to technology. Moreover, there is a tendency to the Non-bio applications in almost all descriptors of this category.
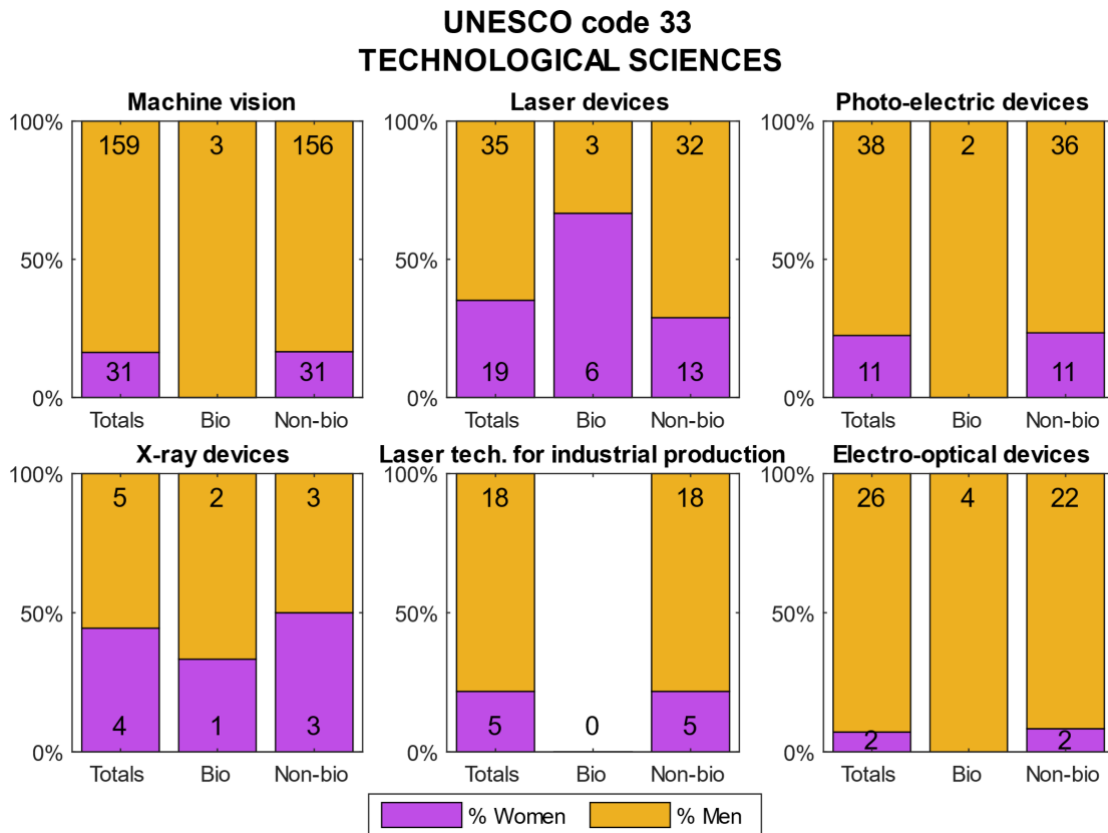
UNESCO code 33
TECHNOLOGICAL SCIENCES

Figure 12. Bar chart, differentiating between women (purple) and men (orange) for six UNESCO codes belonging to category 33 (Technological Sciences).
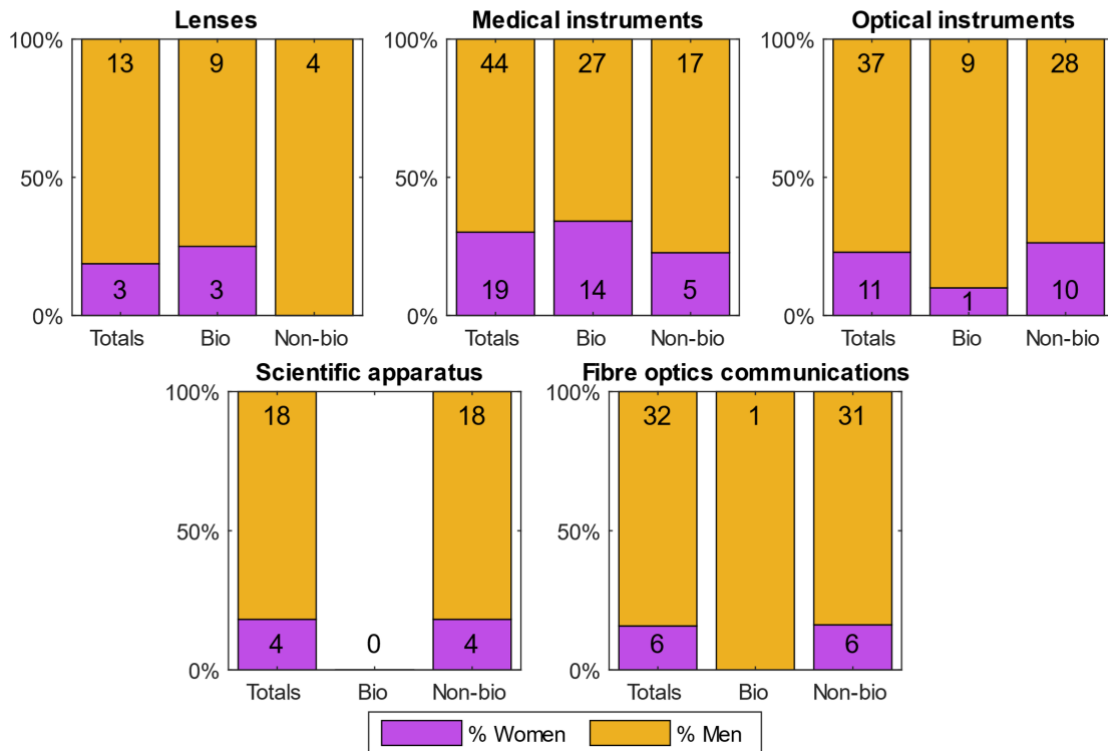
UNESCO code 33
TECHNOLOGICAL SCIENCES

Figure 13. Bar chart, differentiating between women (purple) and men (orange) for five UNESCO codes belonging to category 33 (Technological Sciences).

To sum up, in Figure 14 we depict the total numbers divided by category. Note that those numbers are not the sum of all the descriptors in each category, but a bit less in some cases due to the fact that the same thesis can be assigned to more than one descriptor and, if they correspond to the same category, it is necessary to delete the duplicated theses in order to show each thesis once in this figure.

In this case, a balanced distribution of men and women occurs in "Chemistry", "Life Sciences" and "Medical Sciences". Note that those categories are more related to biological applications than other categories. On the other hand, the percentage of women in the "Earth and Space Sciences" category does not achieve a 20% of the total. When distributing the theses into Bio or Non-bio applications, the percentage of women is bigger in the Bio application in all groups except for "Earth and Space Sciences" where any woman is defending her thesis with a biological or clinical application and only one man does. Moreover, there is a balanced distribution in almost all the cases analyzed in the biological field. However, when analyzing the Non-bio theses, a balanced distribution can be only seen in "Chemistry" and the percentage of women is 20% or less in "Life Sciences" (where no women are defending thesis with a technical nature), "Earth and Space Sciences" and "Technological Sciences" categories.

It is remarkable the fact that in technological categories, such as "Astronomy and Astrophysics", "Physics", "Earth and Space Sciences", and "Technological Sciences", there are more male authors in contrast with the other categories where the participation between women and men tends to equalize.
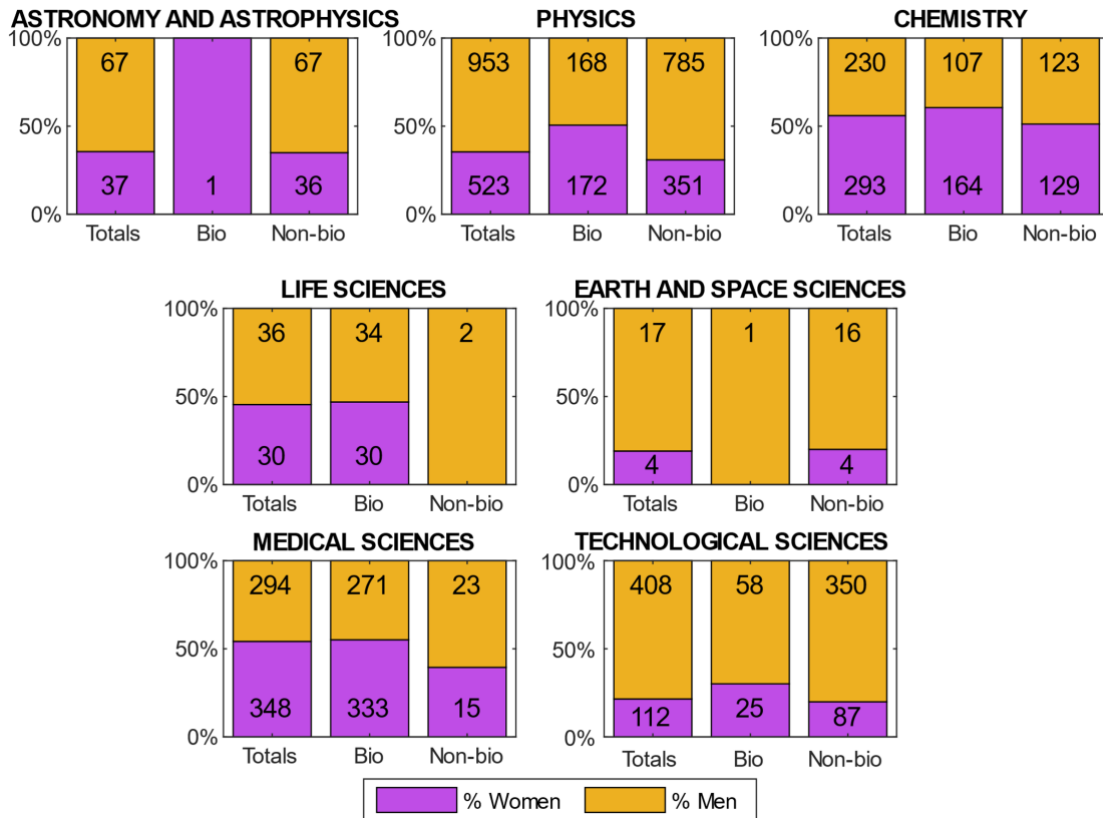
Figure 14. Bar chart, differentiating between women (purple) and men (orange) for all categories evaluated.

In summary, for each thesis carried out by a woman, there are 1.49 theses defended by men, so more than half of the analyzed theses in this work were carried out by males. In addition, while in the theses conducted by males there are 68% of them labeled as Non-bio, only 46% of the theses are labeled as Non-bio when they are conducted by females.

4. Discussion

The data analysis shows a particularly underrepresentation of women at doctorate programs in Optics and Photonics related to the UNESCO codes of "Astronomy and Astrophysics", "Physics", "Earth and Space Sciences", and "Technological Sciences". Moreover, in all of these categories, there are few Ph.D. programs targeted as Bio. In contrast, a gender-balanced situation exists in the UNESCO codes of "Chemistry", "Life Sciences", and "Medical Sciences", where biological or clinical Ph.D. programs dominate.

The disparities in Bio or Non-bio Ph.D. programs are more evident in the category of "Physics", whose descriptors appear in the vast majority of the theses in Optics and Photonics. We identify that the underrepresentation of women is significantly increased in Non-bio Ph.D. programs in most of the descriptors of the "Physics" category. Some of the key descriptors following this trend are "Electromagnetic waves", "Interaction of electromagnetic waves with matter", "Optics", "Fibre optics", "Lasers", "Physical optics", "Digital image processing", and "Photochemistry". Then, this trend also applies to the categories of "Astronomy and Astrophysics", "Earth and Space Sciences", and "Life Sciences". In the category of "Technological Sciences", the descriptors of "Laser devices" and "Medical instruments" also show a better gender balance in Bio Ph.D. programs, whereas in the other descriptors women are underrepresented both in Bio and Non-bio Ph.D. programs. On the other hand, in the categories of "Medical Sciences" or "Chemistry", where the overall presence of women is higher, there are no important differences in terms of the character of the Ph.D. program.

5. Conclusions

The data presented in this article demonstrate that we need to be aware of the gender bias affecting certain subfields of Optics and Photonics, particularly the Ph.D. programs within the field. Within each descriptor, women tend to approach a clinical or biological program, whereas the proportion of women in technical

programs is scarce. Moreover, the proportion of women is significantly lower in the categories of "Physics", "Astronomy and Astrophysics", "Earth and Space Sciences", and "Technological Sciences". This contrasts with the gender-balanced distribution in "Chemistry", "Life Sciences", and "Medical Sciences". Further studies and measures to tackle the causes of the gender gap in scientific disciplines are required.

Though the analysis is constrained to Spain, we believe that the conclusions can be generalized to a wide number of countries, especially in Europe and America, where most cultural and organizational aspects are shared with Spain. Besides, further studies can be addressed to assess the situation in different countries.

In order to reduce the gender gap, policies and projects with a gender perspective must be encouraged. Measures such as increasing the visibility of women in conferences or workspaces can be applied [27]. Also, by noticing the subfields or topics which are particularly affected by gender bias, we can apply more specific measures such as the search of female referents within this subfield.

Acknowledgements

Appendix

Here can be seen the name of each descriptor analyzed together with its UNESCO code in different tables divided by category.

Table A.1. Descriptors analyzed in the "Astronomy and Astrophysics" category.

210115 - X-ray sources	210302 - Telescopes
210300 - Optical astronomy	210303 - Astrophysical spectroscopy
210301 - Position astronomy	

Table A.2. Descriptors analyzed in the "Physics" category.

220204 - Electromagnetic waves	220914 - Optical properties of materials
220205 - Gamma rays	220915 - Optometry
220206 - Infrared, visible and ultraviolet radiation	220916 - Photographic instrumentation
220207 - Interaction of electromagnetic waves with matter	220917 - Photography
220212 - X-rays	220918 - Photometry
220308 - Photoelectricity	220919 - Physical optics
220611 - Laser molecular spectroscopy	220920 - Radiometry
220801 - Beam handling	220921 - Optical spectroscopy
220802 - Beam sources	220922 - Ultra-violet radiation
220900 - Optics	220923 - Visible radiation
220901 - Optical absorption spectroscopy	220924 - Physiological optics
220903 - Colorimetry	220925 - Digital image processing
220904 - Optical emission spectroscopy	221007 - Electronic spectroscopy
220905 - Fibre optics	221020 - Molecular spectroscopy in physical chemistry
220906 - Geometric optics	221022 - Photochemistry
220907 - Holography	221113 - Interaction of radiation with solids
220908 - Illumination	221116 - Luminescence in solids
220909 - Infrared radiation	221124 - Optical properties of solids
220910 - Lasers	221132 - Spectroscopy of solids
220911 - Light	221211 - Photons
220912 - Microscopes	221213 - Electromagnetic radiation
220913 - Non-linear optics	221402 - Metrology

Table A.3. Descriptors analyzed in the "Chemistry" category.

230101 - Absorption spectroscopy	230112 - Optical microscopy
230105 - Emission spectroscopy	230113 - Microwave spectroscopy
230106 - Fluorimetry	230114 - Phosphorimetry
230108 - Infrared spectroscopy	230117 - Raman spectroscopy
230109 - Magnetic resonance spectroscopy	230120 - X-ray spectroscopy
230110 - Mass spectroscopy	

Table A.4. Descriptors analyzed in the "Life Sciences" category.

240605 - Biooptics	241115 - Physiology of vision

Table A.5. Descriptors analyzed in the "Earth and Space Sciences" category.

250102 - Atmospheric luminescence	250123 - Radioactive transfer
250108 - Atmospheric optics	

Table A.6. Descriptors analyzed in the "Medical Sciences" category.

320109 - Ophthalmology	321309 - Ocular surgery
320115 - Diagnostic imaging	

Table A.7. Descriptors analyzed in the "Technological Sciences" category.

330420 - Machine vision	331109 - Lenses
330707 - Laser devices	331110 - Medical instruments
330709 - Photo-electric devices	331111 - Optical instruments
330723 - X-ray devices	331113 - Scientific apparatus
331008 - Laser technology for industrial production	332511 - Fibre optics communications
331104 - Electro-optical devices	