Physics and humanity: the advancement of women in physics at universities

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Abstract. The physics community of practice has been active at many levels in promoting the advancement of women. However, the percentages of women in university departments remain generally lower in physics than in the life sciences. Arguments relating to teaching and research loads and work-life balance are comparable in these disciplines. This paper provides some review material on why the advancement of women is relatively slow in physics. Several useful concepts and recent changes are summarised. It is suggested that relevant dominant factors that differ across these fields are perceived gender bias in the fields, the belief that innate talent is a prerequisite, combined with the stereotype that women do not possess this talent, and the effects of the lower percentages of women physics. Regional influences are known to exist in gender gaps in access to resources, and to opportunities, from the Global Survey of Physicists, 2011, but these gaps do not conform to the gender equality paradox. The Global Survey of Mathematical, computing, and Natural Scientists, which will be concluded in 2019, is described since its results will shed light on the contrast between fields.

1. Introduction

The proportions of women in physics across the globe are in most cases lower than the proportions of women in the life sciences. An example of the contrast among first qualifications may be provided from the Integrated Postsecondary Data Collection System of fractions of bachelor's degrees earned at universities in the United States of America (USA), showing that in 2015, the fraction of women earning degrees in physics was below 20%, while the percentage of women obtaining degrees in the biological sciences was approximately 60% [1]. As a complementary example at senior career levels, a survey of 69 national academies showed that the mean share of membership numbers by women in the biological sciences is 22%, while for physical and chemical sciences the mean share is 9% [2].

Vigorous initiatives have been in action across the globe for several decades within the physics community to increase and encourage the participation in physics by women. Summaries of the status and progress of women in physics may be found in the proceedings of many conferences, notably those held by the International Union of Pure and Applied Physics [3, 4, 5, 6, 7]. These cover a landscape of interventions, ranging from national laws, institutional policy, and departmental charters, through actions to improve the attractiveness of the workplace and improve selection practices, to finding best practice in teaching and learning to encourage girls to enter science and physics.

In this paper, we suggest a way forward for answering two questions: 1. What fundamental concepts are useful for physicists in understanding gender in science, and particularly, for increasing the participation of women in university physics through teaching and learning? 2. There appears to be a larger fraction of women in the biosciences, in comparison with physics. What can the physics community learn from the contrasts? In investigating the second question, studies of gender gaps in the context of many nations are useful, and will show that the gender equity paradox can be tested with some aspects of the Global Survey of Physicists, 2011.

A set of fundamental concepts is proposed for the first question. The focus of this work is on global or universal applicability, and is it not the aim of this work to provide a detailed review of the many helpful initiatives that have been developed in different regions. Answers emerging from the literature are highlighted for the second question. A global survey that may shed light on the similarities and contrasts between the physics and life science disciplines is described.

2. Initial remarks

In seeking to understand the difference between life sciences and physical sciences, a set of concepts from the broader literature prove to be useful. A few preliminary remarks are made at this stage.

In this paper, only binary gender is addressed. Many of the concepts affecting women and gender are applicable to other identities including race, and intersectionality. These are not addressed here.

Generalisation can be useful in achieving broad aims for women or men, but can also be offensive or polarizing. It is recognized that distributions of attributes and opinions exist within the broad group of women, and also that general conclusions drawn from the broader literature may be inapplicable to scientists, as a subset, but might form a reasonable starting point for enquiry.

The deep differences in culture across the globe have an influence on access to, and participation in, science. It has been stated that "knowledge of science and technology is universal, but it is shaped by local culture" [8]. Statements on the Universality of Science have been made by the International Council for Science and the International Union of Pure and Applied Physics. Broader aims are declared in Sustainable Development Goal 5 [9]. These statements are useful in understanding and motivating the participation of women in science.

It is essential in surveys of this kind for natural scientists to work with social scientists, and this has been done in the Global Survey of Physicists, through the Statistics Division of the American Institute of Physics, and in the current survey described below.

In contrasting the experiences of women and men, both groups should be considered; this is a point that is sometimes not taken into account in surveys. Both men and women become parents. The sharing of the responsibility of parenthood is one of the most controversial issues across the world. Change cannot be achieved by women alone; nor is the point of change to achieve dominance. The aim is to achieve better work environments for both men and women.

3. Some useful concepts for physicists

3.1. Gender schemas

A concept that has been found to be particularly useful as a basis for understanding gender gaps is that of the schema. Gender schemas are hypotheses that affect the expectations of men and women, and their performance at work [10]. Negative aspects of schemas are familiar as stereotypes, but schema is a neutral term. Implicit stereotypes and schemes are unconscious attributions, while explicit stereotypes are conscious and controllable. Humans seek explanations of the physical and social phenomena around them; in physics, hypotheses are formed and tested, but in interpersonal interaction, schemas may go untested and unrecognized, even by physicists. The process of forming identity through social interaction is well captured by the saying known in South Africa: "Umuntu ngumuntu ngabantu" in Zulu, which conveys, in one interpretation, that we learn who we are through others. Two relevant schemas are the "agentic" schema, characterized by behavior that is proactive, independent, and assertive, and the "nurturative" schema, describing association with children, nurturing behaviour, and connection with soft issues. These two schemas may, in the work environment, be confused with gender schemas, leading to the assumption that the female physicists present should take the nurturing role rather than the agentic role.

In the university context, an example may be given of the professor. The professor is expected to exhibit independence in research and teaching, assertiveness in relations with students, and proactivity on behalf of the university and the department. The professor also guides young people, mentors students, and builds the collegial environment, and therefore fulfils nurturative roles. Being under-represented, or a minority, in the workplace enhances the possibility of encountering conflicting schemas. Misplaced schemas lead to under-evaluation, particularly of women [10].

Women are socialized with the same schemas as men. Unconscious bias has been shown to be exhibited by women as well as by men in selection of university staff. A frequently cited early study on this topic was carried out within the psychology community, in which curricula vitae were sent to university psychologists across the USA for consideration for a junior academic job, and for tenure [11]. Results showed that both men and women were significantly more likely to hire a man than a woman with an identical record for a junior post, at the time of the paper.

3.2. Cumulative disadvantage

A particularly useful concept for minorities in the workplace is that of cumulative disadvantage [10]: minor inequities add up to long term consequences. Examples occurring in meetings are frequently related in anecdotal form by women, where their voices and contributions may be ignored – sometimes unconsciously – by a chair. More serious occurrences include allocating less challenging assignments to women, often with benevolent intentions.

3.3. Relevant factors change over time

Changes in academic circles and in the underlying society take place, and interventions that were historically important may no longer be relevant. A review in 2011 [12], aimed at understanding the underrepresentation of women in mathematics-related fields, encompassed discrimination in journal reviewing, grant allocation, and job selection in North America and Europe. Although change had been achieved by 2011 in comparison with 1970, numbers remained low in mathematics-related fields. Discrimination against women as authors of papers, grant holders, and in selection processes has been cited in earlier studies, but evidence in this study in 2011 indicated that these factors were no longer dominant in these regions. The authors concluded that, in the region reviewed, initiatives to combat discrimination against women had been successful; that given equal resources, men and women do equally well under review, in publishing, and in career development, but that underrepresentation could be attributed to differences in resources, abilities, and choices.

3.4. Resources and choice

In the study cited [12], women occupied positions with lower availability of resources. The authors linked this to choices made by women of whether to raise children and when, whether to follow relocations of their spouses, whether to take on elder care, and how to manage work-home balance.

3.5. The percentage of women declines with seniority

A plot of the percentage of women in a field against seniority or age is an informative tool. The present author has not yet seen data from any country in which the fraction of women in physics does not decline with seniority. The reasons why women leave fields at a higher rate than men are critical to this discussion and are part of the key to the debate.

3.6. Family care

The association of the nurturative schema solely with women is perpetuated the assumption in most societies that women are responsible for family care. It is relatively rare to find national laws and institutional policies that do not assume that women are solely responsible for child care [13]. Interventions such as career breaks for child care, and "stopping the clock" for career breaks, are made available to women more frequently than to men. Gender stereotyping is reinforced, rather than mitigated, in this way.

3.7. Physics identity
To combat the "outsider" identity often encountered by women, the "physics identity" concept has been used to cover the developing understanding of one's own learning and the transition from "physics student" to "physicist" (a review will be found in [14]). Physics identity overcomes the "outsider" identity for many women.

3.8. Departmental atmosphere
A critical part of developing a sense of belonging in the field and ownership of the physics program is related to the welcoming atmosphere in the departments encountered. The concepts were well-set out in the Spin-Up review [15], which established workable guidelines and interventions for encouraging women and underrepresented populations to study physics in the USA. In the United Kingdom (UK), Project Juno [16] and Athena-SWAN developed a Code of Practice that may be voluntarily adopted by departments. The International Union of Pure and Applied Physics (IUPAP) Working Group on Women in Physics is developing the Waterloo Charter, and the Baltimore Charter has been formulated for astronomy. A number of physical societies have developed helpful guidelines on, for example, career break management [17].

3.9. Factors influencing career choices
Many studies have been conducted on career choices. A recent study on college choices in the USA sought the common attributes that cut across academic disciplines that are predictive of the choice of major subjects in bachelor's degrees [18]. While only 20 university subjects participated, the results may be of interest in wider studies. Choice was explored based on the extent to which each major was perceived to exhibit each of six specific traits: maths orientation, science orientation, gender bias against women, helpful orientation, money orientation, and creativity orientation. Perceived gender bias against women was the dominant predictor for choice of majors in this study.

Stoet and Geary (2018) [19] suggest a mechanism for educational and career choices prompted by an observation of the regional dependence described in section 3.11. Students do consider their own perceived ability or self-efficacy, and their own enjoyment of the subject, as well as the merits and risks of entering different academic paths within their social context. During the study, boys were observed to express more self-efficacy in STEM than girls.

A fear of joining a community that is male-dominated has been cited [20]. The low fraction of women on faculty is apparent in many countries (e.g. Cameroon [21]) and representation of women in prestigious roles is smaller in many nations (e.g. India [22]).

3.10. Intersectionality
The field of intersectionality examines how systems of power interact in the marginalization of communities, including the intersection of gender with other marginalized identities, such as sexuality, race, class, and caste, among others [23]. Amplification of intersectional marginalisation in Artificial Intelligence is described in the work of Buolamwini and Gebru [24] cited below, who concluded that the confidence with which face recognition makes correct identifications varies with both sex and skin tone.

3.11. Regional and economic factors
Many physicists live and work in countries with significant poverty. In many cases, they have succeeded in making a new life for themselves and their families through engagement with the sciences. Inclusion of countries with diverse economic conditions in the scientific community, through international organizations, publishing practices, conferences and collaboration, is an important part of the development of science as a whole.

Stoet and Geary [19] analysed the 2015 results of the Programme for International Student Assessment (PISA) [25] from 71 nations in the science, technology, engineering, and mathematics (STEM) fields. Countries with high gender equality, measured through high Global Gender Gap Indices [26], tended to exhibit higher gender gaps in science, including STEM graduation gaps. The last conclusion is surprising, and has been named the gender equality paradox. Stoet and Geary put forward a mechanism for educational and occupational choices involving broad contextual influences as well as personal strengths and attitudes, and suggest that the gender equality paradox may arise from a perception that a STEM career may be a well-paying investment with a secure future in low GGGI nations.

Some additional observations and challenges have been made in connection with these conclusions. For example, in a study of 66 nations, it was concluded that gender-science stereotypes may be reinforced if men predominate in a given field, even in nations with high gender equality [27].

The liberty of choosing a career is not always available to women. The experiences of women in physics, described in conference papers on progress in their counties, testify to the determined spirit of women physicists in making progress under difficult circumstances. In Pakistan, as an example, it is known that many more women wish to study postgraduate physics than are allowed to do so by parents, given that a suitable marriage match may be found for them [28]. The subordinate role of women has been specifically cited as making the study of physics difficult in Zimbabwe [29]. The traditions that household chores are for girls and women are strong [30]. The work cited illustrates the courage and fortitude of colleagues in these countries.

3.12. Interventions should benefit both women and men
Once again, it is important to emphasize that interventions fail if they do not make the work environment better for all, and not just for women. The factors identified by Jordan et al. in 2003 [31] are still relevant today, and specifically include respect for people and commitment to critical thinking.

The changing roles of men in the USA, specifically in biology and physics, have been explored by Damaske et al. [32]. The authors have found changing norms of fatherhood among men in the USA, with an increasing belief that that home life is not the sole concern of women. A growing number of men seek egalitarian relationships at home. They experience difficulty in finding work-family balance, and seek flexible academic environments.

4. The Global Survey of Physicists, 2011
It has been the practice of the IUPAP Working Group on Women in Physics to make sure that as many countries are represented at conferences as possible, especially including developing countries, countries with few physicists, and island states.

As a result of discussions in this environment, a global survey of the experiences of both men and women in the field of physics was undertaken in 2010-2011 [33, 34], and forms part of the background for this paper. The survey was available in eight languages. The final number of respondents was 14934, covering 130 countries. Results were contrasted for low Human Development Index (HDI) and High HDI countries, using the prevailing United Nations definitions for those terms.

The Global Survey of Physicists did not provide numbers and percentages of women in physics, but was focussed on similarities and contrasts in the experiences of women and men in the field. The survey addressed educational background, early career experiences and current employment, and the balances between marriage, career, family and housework. The results provide valuable data on which to base decisions.

4.1. Family care and career breaks
There was a stark contrast between the percentages of women and men who had had significant breaks in their doctoral studies, the data being limited to those who had their first child during these studies. Career breaks affected 55% to 65% of women, and 15% to 30% of men. The implications include the recognition of career breaks, the provision of advice on how to manage career breaks, and care in the

definitions of "Young Scientist" awards. It had also been suggested that excellence can be assessed using performance proxies other than counting papers. These and similar factors, however, do not address the difference between life science and physical science numbers.

4.2. Access to resources and opportunities depends significantly on gender
The survey included questions on the resources and opportunities available to the respondents Data are reproduced in Tables 1 and 2 [33]. Even when data are corrected for cohort effects, this survey showed that women reported significantly fewer opportunities to give an invited talk, attend a conference abroad, conduct research abroad, act as a manager, serve as a journal editor, serve on grant agency committees or institute or company committees or organizing committees, advise graduate students, or serve on thesis committees. The only category in these questions in which women and men reported comparable opportunities was that of advising undergraduate students. This gap may be explained by HDI, age, or employment differences, but the fact remains that the nurturative schema for women in physics is reinforced among students and in departments by awareness of these gaps.

4.3. The workplace environment and departmental atmosphere
Women were significantly less likely to rate their relationships with their supervisors as excellent. Women respondents were less likely than men to feel comfortable raising concerns with their bosses or managers, and this effect is larger in low HDI countries.

4.4. Regional and economic factors
In the Global Survey of Physicists, 75% of the countries had a high HDI. The development level of a country showed significant influence on some factors. For example, about 60% of women with children in High HDI countries had their children after doctorate, whereas the comparable figure for the low HDI countries was about 30%.

Some of the responses from the Global Survey of Physicists on opportunities and resources have been considered in the context of the gender equity paradox. If the STEM graduation gap is smaller in countries with a low Global Gender Gap Index, would gaps in access to opportunities and resources also be smaller in low HDI countries? Ivie and Tesfaye [33] published the percentages of respondents replying "yes" to the questions on access to key resources and to career-advancing opportunities. These data are reproduced in tables 1 and 2. It is noted [33] that a cohort analysis has been conducted on the data in Table 2 to test whether gender differences appearing as a result of age, type of job, and/or HDI. In four instances, this was the case. In the remainder, the gender difference was a sufficient explanation. For the purposes of this paper, a "gender gap" parameter has been defined by subtracting the percentage of women answering "yes" – these resources and opportunities are available – from the percentage of men answering "yes". The gender gaps are compared across lower and higher HDI countries.

Table 1. Resources: % of respondents who answered "yes" to sufficient access

	Lower HDI			Higher HDI			Larger Gender Gap
	women	men	gap	women	men	gap	
Funding	34	51	17	52	60	8	lower HDI
Office space	64	74	10	72	77	5	lower HDI
Lab space	42	47	5	46	52	6	~ [a]
Equipment	42	49	7	58	64	6	~
Travel money	31	47	16	57	64	7	lower HDI
Clerical support	22	38	16	30	43	13	lower HDI
Employees or students	42	53	11	33	43	10	~

[a] comparable

Table 2. Opportunities: % of respondents who answered "yes" to sufficient access

	Lower HDI			Higher HDI			Larger Gender Gap
	women	men	gap	women	men	gap	
Given a talk at a conference as an invited speaker	51	67	16	58	73	15	~ [a]
Attended a conference abroad[b]	75	81	6	83	87	4	lower HDI
Conducted research abroad	54	71	17	61	69	8	lower HDI
Acted as a boss or manager	38	53	15	46	61	15	~
Served as editor of a journal	16	24	8	11	19	8	~
Served on committees for grant agencies	22	37	15	26	36	10	lower HDI
Served on important committees at your institute or company[b]	50	62	12	48	60	12	~
Served on an organizing committee for a conference in your field[b]	48	59	11	48	55	7	lower HDI
Advised undergraduate students[b]	82	84	2	69	74	5	higher HDI
Advised graduate students	63	77	14	58	70	12	lower HDI
Served on thesis or dissertation committees (not as an advisor)	52	66	14	37	52	15	~

[a] comparable
[b] better explained by age, human development index, or employment differences than by gender

From both tables it appears that the only opportunity for greater access in which the gender gap, as defined for these tables, is larger in countries with a higher HDI is that in advising undergraduate students. In other categories, the gender gap is larger in countries with a lower HDI. In terms of opportunities and access to resources, this survey does not exhibit the gender gap paradox. Further work, using the GGGI with these data, may prove interesting.

4.5. A follow-up survey is needed

This survey did not seek to contrast disciplines, but this is a goal of the next project, covered in section 5 below. A new global survey is needed to guide actions. Eight years have passed since the Global Survey of Physics. Many, many initiatives have been directed towards increasing the participation of women in science and physics, and it is hoped that they have had impact.

5. Recent developments

5.1. Global

The global environment for women, and for women in science, is changing. The effects are felt in both high HDI and low HDI countries.

Some key geopolitical issues that affect women are as follows [35]. An "abandonment of the liberal order" is observed in many countries. A political culture in which debate is framed largely by appeals to emotion, disconnected from the details of policy, and by the repeated assertion of talking points to which factual rebuttals are ignored ("post-truth politics"), makes evidence-based reasoning increasingly difficult in some nations.

Conditions for women are worse in some countries due to changes of culture, because (1) the underlying culture has not changed in terms of its former gender schemas, or (2) former schemas have been given new expression in a shifting political landscape, or (3) the incursion or imposition of a culture which denies freedom and education to women has reduced opportunities for women, and in the worst case has caused academics to flee from persecution and conflict [36]. During times of high economic threat, prejudice rises significantly. It is likely that in countries where evidence-based reasoning is deprecated, a return to conservative gender schemas in allocating science funding will be experienced.

There is now clear evidence that the earth's climate is changing rapidly. Climate change has been shown to have more impact on the lives of women than on men [37]; disasters kill more women than men, especially where the socioeconomic status of women is low. Health risks show gender differences, and women and girls disproportionately suffer malnutrition when food security and water security are affected. It is expected that mass displacement will exhibit a gender gap as well.

A growing voice against sexual harassment is being heard across the globe. A recent inter-academy report recommends going beyond compliance responses, and focusing on culture in academia; scientific societies have a positive role to play in changing this aspect of culture [38].

It appears that the percentages of bachelor's degrees awarded to women is declining or stagnating. This trend is visible from 2005 onwards in, for example, data collected by the American Physical Society for universities in the USA [1, 39].

5.2. Artificial intelligence

Comments on the nature of prejudice have been made above, but new developments are taking place with the increased use of Artificial Intelligence (AI). Machine bias, programming that assumes the prejudice of its human creators through its algorithms or data sets, is having observable effects in AI applications [24]. Examples are in screening job applicants, or in providing browser advertisements online. The consequences are that women may be presented, for example, with more opportunities for nursing jobs, while men are provided with openings for doctors. A body of work on the subject is growing through groups such as FATE: Fairness, Accountability, Transparency and Ethics in AI.

The assumptions built into AI are examples of logical fallacies, notably the appeal to tradition ("this is right because we have always done it this way") and the appeal to probability ("we can take this for granted because it is probably the case"). Both fallacies have surfaced in recent debates about the inclusion of women in high-energy particle physics [40].

6. Physics and Life Sciences

6.1. Professional role confidence and self-efficacy

Several publications have dealt specifically with the contrast between physics and the life sciences. Ecklund et al. [41] performed a wide survey of scientists in the two fields. The study explored sex-typing (the notion that some jobs are more appropriate for men or women only) and master status (status that has exceptional importance for social identity). In terms of explanations of the difference in numbers related to choice, the study found that men and women had few differences in terms of natural aptitude, but that women were inclined to rate their own performance lower than men with the same aptitude. Professional role confidence plays a significant role in career selection.

The conclusions of the study were the following. First, gender was a salient predictor of the biology-physics choice, and that this is influenced by perceptions of mentoring and discrimination. Secondly, more than half the women in the study had experienced attempted discouragement from pursuing physics at some stage. Third, gender appeared to be the master status influencing the choice of major, rather than scientist identity.

6.2. Perceptions of time commitment, bias, discouragement, and discrimination

Perception of the time commitment required differed between physics and biology; there is a perception that a career in life sciences may be more compatible with family than one in physics [41]. A sense of isolation was reported for the physics environments, while there was certainly a perception that women were evaluated less favourably than men due to implicit bias in physics.

6.3. *The influence of the fraction of women in the field*

In fields with a high fraction of men, individuals may see women as counter-stereotypical, and may sub-type them as being exceptional both in the exertions they have made and in the paths they have followed [27]. The fact that students encounter more women in the life sciences than in physics departments is likely to change explicit stereotypes, but it has been shown that students and entrants to continue to hold implicit gender stereotypes associating science with men.

Smyth and Nosek [42] showed that lower proportions of females in a given field of science correlate with stronger implicit stereotypes of "science-is-male", whereas the explicit, conscious stereotype may be weakened by working in a field which clearly has a high fraction of women scientists. Martinez et al. [43] have found that women report more gender-based discrimination and sometimes harassment, fewer external job offers, and fewer internal retention offers than their male counterparts, but the studies cited above indicate that schemas and stereotypes have enduring roles to play.

6.4. *Perceptions of innate talent*

Recent work has been performed which implies that expectations of a cardinal role for innate talent are higher in physics than in biosciences. These combine with stereotypes that women lack the high-end aptitude for mathematics and physics [44]. A correlation was found between the representation of women in a field and the extent to which practitioners believed that success depends on sheer brilliance in that field. Prejudice related to innate talent also surfaces in work by UNESCO [45].

7. The Gender Gap in Science Project

In 2016 the International Council for Science (then ICSU, and now ISC) funded three collaborative projects. One of these is "A Global Approach to the Gender Gap in Mathematical, Computational and Natural Sciences: How to Measure it, How to Reduce it?". This project has eleven international partners. The project [30] is led by the International Mathematical Union IMU, with IUPAC (the International Union of Pure and Applied Chemistry) and IUPAP as executive partners. The project partners include in addition IAU (Astronomy), ICIAM (Industrial and Applied Mathematics), IUBS (Biological Sciences), UNESCO (United Nations Educational, Scientific and Cultural Organization), IUHPST (History and Philosophy of Science and Technology), ACM (Computer Science), GenderInSite (Gender in Science, Innovation, Technology and Engineering) and OWSD (Organization of Women for Science for the Developing World).

The project consists of a global survey of mathematical, computing and natural scientists, a joint data-backed study of publication patterns, and a database of good practice for girls and young women, parents, and organisations. It may well shed light on similarities and contrasts in the experiences of women and men in different disciplines, and provide insight into the questions asked above – particularly about contrasts between the life sciences and the physical sciences.

7.1. *Survey*

The survey is designed to provide longitudinal results in conjunction with the earlier Global Survey of Physicists, described above. Particular care was taken to expand the earlier survey. Both surveys are based on snowball samples, and are not intended to provide percentages of women in disciplines or fields. It is noted that this role is complementary to that of quantitative surveys, including the UNESCO SAGA surveys [31, 32] and PISA results [25], and work on comparing the types of survey is likely to yield insight.

The survey was provided in English, French, Chinese, Japanese, Russian, Spanish, and Arabic. Because this work covers global cultures and diverse scientific communities, particular care was taken to make sure that the questions were likely to reflect the realities of life across the continents. Three regional workshops were held, in Africa, Asia, and Latin-America and the Caribbean. A principle of the project is that it includes men as participants, organizers and representatives at the workshops. The participating countries were, in South Africa: Algeria, Burkina Faso, Botswana, Cameroon, Ethiopia, France, Kenya, Lesotho, Morocco, Madagascar, Malawi, Nigeria, South Africa, Swaziland, Uganda, the

United States and Zimbabwe; in Taiwan: Australia, China, France, India, Israel, Japan, Korea, Nepal, Malaysia, Taiwan, Thailand, and the United States; and in Colombia: Argentina, Brazil, Chile, Colombia, Costa Rica, Cuba, El Salvador, Mexico, Peru and the United States.

Each workshop provided additional insight to relevant questions. In Africa, participants requested that questions on career disruptions should include health, conflict, natural disasters, and other continent-specific answers, and Arabic was added as a language. In Asia, an emphasis on participants in industry emerged and the survey was expanded to included professionals and industrialists. In Latin America and the Caribbean, a focus on youth and young scientists emerged from an exchange session on the special needs of young people.

The survey was released in May 2018 [46]. Translation and analysis will take place in 2019.

7.2. Joint data-backed study on publishing patterns

The Gender Gap project is also based on recent work by data scientists Mihaljević-Brandt et al. (2016) [47]. In this recently published study, the relatively low percentage of women publishing in mathematical journals was highlighted. The new study covers all the collaborating disciplines, and once again it is hoped that insights about the gender gap in different disciplines, and change over time, will emerge.

7.3. Database of good practices

The communication of the findings from the tasks above is intended to support good choices of interventions and initiatives, with relevance to the culture from which the data in the surveys is drawn. At the same time, it is recognized that initiatives are routinely reinvented, and seldom professionally evaluated. Therefore, as task to collect and maintain a database of published evaluated interventions aimed at increasing the participation of girls and women in science.

Better career guidance is an additional aim of this task, with emphasis on how to reach the key advisors in the career choices of girls: parents, especially in the developing world, and teachers. This third task is deeply challenging.

8. Conclusions

Two questions were posed above, in the context of teaching and learning at universities, and particularly the representation and progress of women in university departments in physics.

The first question asked what fundamental concepts are useful for physicists in understanding gender in science, and particularly, for increasing the participation of women in university physics through teaching and learning. The set of concepts introduced above was aimed at providing a basis for the next question.

For the second question, there are indubitably lessons to be learned by the physics community from its life sciences counterpart. A deterring factor of perceived gender bias in physical science departments has been observed, and the fear of joining a field with a visible predominance of men appears to be a factor, particularly in terms of perceptions of possible isolation, discrimination, and under-evaluation. This may constitute of schema which requires attention.

Perceptions of time commitment appear to be different between these two fields.

The expectations of innate brilliance in a field, combined with a stereotype that women lack innate ability in mathematical sciences, appear to affect the career choices of women, and to differ between physics and the life sciences. Women in physics may be regarded as exceptional in the existing schemas. It is therefore relevant that self-efficacy and professional role confidence appear to be expressed less often by girls.

The Global Survey of Physicists indicated significant gaps in access to resources and experience between women and men. The interpretation of the results of this survey does not appear be consistent with the gender equality paradox in terms of gender gaps in access to resources and opportunities: gender gaps are larger, with women at a greater disadvantage, in nations with a lower Human Development Index, in all the cases considered except undergraduate teaching.

It will be of considerable interest to discover how these gaps have evolved in the years from 2011 to 2019. It is hoped that it will be possible to discern, from the results of the Gender Gap survey, which aspects are dominant in contrasts between physics and biology.

Given the discussion above and the questionnaire used, it should also be possible to distinguish whether there are significant differences across physics and biological sciences in experiences in family care, and whether career breaks slow or speed up careers significantly. The results will show whether access to resources depends on gender to the same extent in these fields, and whether there is a significant difference in the workplace environment and departmental atmosphere. To a lesser extent, the analysis may indicate whether there are contrasts in perceptions of time commitment, or experiences of discouragement, discrimination or harassment. This survey should also indicate any contrasts in opportunities for the scientific growth of individuals, and in opportunities for employment. Some evidence of contrasts of regional and economic factors on these questions may emerge.

It is hoped that the Gender Gap bibliometric study will reveal whether there are different publication patterns between physics and biological sciences, and that the task on best practice will shed light on what interventions are appropriate for the next decade that physics can learn from biology, as well as across different cultures and regions.

The vision for the future of physics in terms of gender is that welcoming departments will succeed in maintain an equitable gender balance among staff and students, across the global community.

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