Paving the way and passing the torch: Mentors' motivation and experience of supporting women in optical engineering

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Abstract

The phenomenon of women's underrepresentation in engineering is well known. However, the slow progress in achieving better gender equality here compared with other domains has accentuated the 'numbers' issue, while the quality aspects have been largely ignored. This study aims to shed light on both these aspects via the lens of mentors, who are at the coalface of guiding female engineers through their education and subsequent careers. Based on data collected from 25 mentors (8 men and 17 women from 8 countries), the paper explores their experiences of being mentors, as well as their views on recommended actions for nurturing female engineers. The findings reveal that the primary motivation for becoming a mentor was personal for men and women. Many mentors from countries with relatively lower female labour participation rates perceive their roles as guarantors of their mentees' successful future career paths, and a similar trend can be found in mentors in academia. The study underscores the need for invigorating mentors' roles in order to secure a more equitable future for engineering education.

Keywords

Engineering education, Optical engineering, Cultures and institutions, Gender equality, Mentors and leaders

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Introduction

Persistence of the 'why so few?' question

In the study of women in science, technology, engineering and mathematics (STEM), the question 'why so few?' has been repeatedly asked (Bell 2011, Etzkowitz et al. 2000, Harding 1991, Hopkins 2006, Lewin 2010, Longino and Doell 1983, OECD 2006, Wotipka and Ramirez 2003), and extensively researched in recent years (Ceci and Williams 2010, European Commission 2008, 2009, GenSET 2011, Hill et al. 2010, Ihsen 2005, Lagesen 2007, Leicht-Scholten et al. 2009, US Department of Commerce 2011, Ulriksen et al. 2010).

The 'why so few?' question is even more pressing in engineering and technology (Lane 1999, Powell et al. 2009). Data published by the European Commission indicate a wide variety across STEM subjects as well as across countries. In science, mathematics and computing, the ratio of female PhD graduates is 23 per cent in Japan, and their counterparts in the US and Spain account for 41 per cent and 48 per cent respectively. In engineering, manufacturing and construction, the ratio is almost half for each country (12 per cent in Japan, 24 per cent in the US and 34 per cent in Spain) (European Commission 2012) (Figure 1).

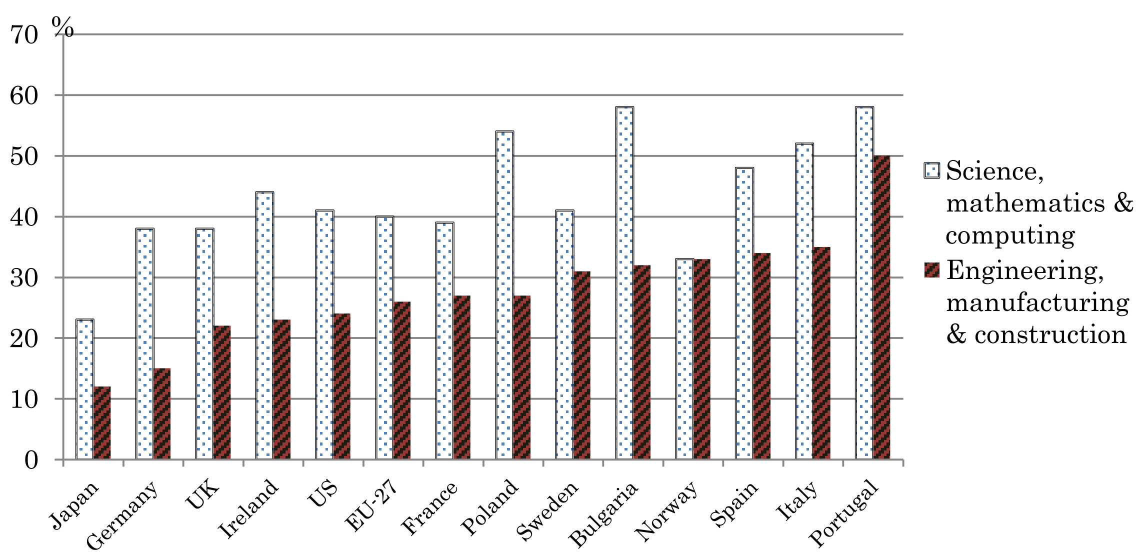

Figure 1. Proportion of female PhD graduates in STEM, 2010 (European Commission, 2012) PhD graduates are defined as ISCED (International Standard Classification of Education) 6.

Evidence suggests that general perception of technology as male rather than female can impact women's access to technology (Spender 1995). The lack of appeal of engineering and technology to girls and young women has caused problems at the entry point. It has been argued that girls' choice of specialisation as well as careers is greatly influenced by social, structural and personal factors (Adya and Kaiser 2006). Social factors include gender biases and stereotypes towards certain career paths amongst friends, family and media, while structural factors encompass the school types people attended (co-ed vs. single-sex) and their science curricula and facilities, and access to suitable role models and mentors. Individual differences (e.g. gender, psychosocial attributes) also matter (Adya and Kaiser 2006). Even when individual girls and women do decide to enter engineering for their own reasons in spite of these barriers, the laboratory environment often has a male-dominated atmosphere, which creates the vicious cycle of the image problem (Beddoes 2012, Powell et al. 2009, Sørensen 1992, Sanders 1995). Blickenstaff (2005) found that these obstacles remain strong largely due to the bias against women and girls in male-dominated STEM environments and their subsequent marginalisation (Blickenstaff 2005, Rosenthal et al. 2011).

The task of specifically attracting more women into engineering (who were not considering it on their own accord) and their retention has also proved to be considerably difficult (Adelman 1998, Faulkner 2000, Fox 2001, Minerick et al. 2009, Wynarczyk and Renner 2006). The recent Global Survey, in which 15,000 male and female physicists from 130 countries took part, also revealed significant gender differences across the world, in terms of professional opportunities, family responsibilities and access to essential resources (Ivie and Tesfaye 2012). Another large-scale, longitudinal study, funded by the National Science Foundation in the United States, investigated the question of why some women left engineering and why some never entered an engineering-related profession after successfully graduating, and why others who had decided to remain in the field subsequently quit (Fouad et al. 2012). In the study, a third of those who left engineering raised the workplace climate and their bosses as their reasons for leaving, while eighty percent of those who did not enter engineering after graduation are working in another field for various reasons (Fouad et al. 2012: 6). These include difficult working conditions (e.g. low pay, lack of viable career path), and their perceptions of the engineering workplace culture as being non-supportive of women (Fouad et al. 2012: 21).

These studies highlight the fact that the obstacles facing women in engineering are multifaceted and have to be carefully examined through the lens of their life-cycle stages (Herman and Webster 2010). The study by Cech et al. (2011) discovered that the strongest psychosocial factor influencing the women students' intentions to remain in or leave engineering was their relatively lower confidence in their ability to carry out the requisite professional roles and competencies than men, rather than their plans to have a family. Amelink and Meszaros (2011) discovered that career expectations formulated through educational experiences as undergraduates play a key role in motivating students to stay in engineering. The slow progress in achieving gender equality in engineering has fuelled the discussions around the underrepresentation of women in the field ('why so few'), and the overall opinion is that in order to see desirable changes occur a rather long-term process of implementing various reforms, including addressing biases in society, is required (Moss-Racusin et al. 2012). In some countries where women are not encouraged to remain in the labour market, these changes may take a longer time than other countries (Sjöberg 2010) (Figure 2).

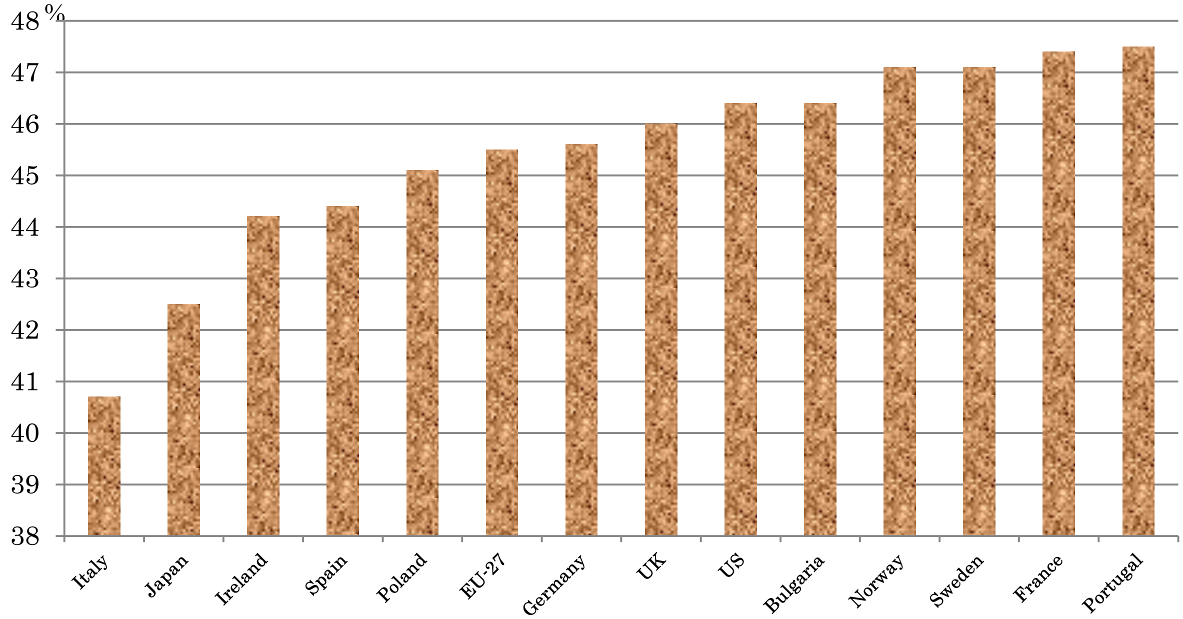

Fig 2 Female Labour Force Participation Rate, 2011 (percentage, ages 15 and over) (World Development Indicators 2013/OECD Labour Force Statistics, 2013)

As a solution, some make a case for the introduction of quotas in order to engineer a rapid change in these numbers. Yet others argue against such a policy, because in order for women to have the desire to enter and pursue STEM for the long term, if not on a lifelong basis, 'there ought to be a mutual attraction between women and scientific fields' (Bouville 2006: 9). A few research findings have started to emerge showing the quality of science production being improved by addressing gender issues (Castaño and Webster 2011, Le-May Sheffield 2006, Osborne et al. 2008, ROSE Project 2007, Schiebinger 2008, Sjøberg and Schreiner 2010, Uriarte et al. 2007). A number of case studies have reported the positive effects of programmes successfully tackling gendered academic research cultures (Sible et al. 2006, Fox et al. 2009, Rhoton 2011).

Shedding light on mentors' roles, and their motivations and experiences

Another major development in recent years is to provide a formal mentoring and role model support programme for women training and working in STEM. In the U.S., formal mentoring support has been promoted by universities such as the Electrical Engineering and Computer Science Department at UC Berkeley, Caltech Women's Center, Virginia Tech's ADVANCE Program, as well as other non-profit voluntary groups, most notably, MentorNet. Mentoring is now widely recognised not only as an important aspect of institutional or organisational support for students or junior members of staff, but also as necessary in order to enhance the chance of a successful career for many particular minorities such as women (Yost et al. 2010, Rosenthal et al. 2011). Furthermore, the importance of women mentoring women for their success in higher education and academic institutions has also been emphasised (Schlegel 2000, Touchton et al. 2008). A critical review of preceding research into mentoring (Crisp and Cruz 2009: 538) identified four major variables that can be acted on to develop a 'good' mentoring programme in business and academia: (i) psychological and emotional support, (ii) support for setting goals and a career path, (iii) support for advancing a mentee's subject knowledge and skills relevant to their chosen field, and (iv) the specification of a role model.

However, preceding studies on mentoring have often been conducted from the perspectives of mentees, or to test the effectiveness of a formal programme in an outcomes-oriented way. (Fox and Fonseca 2006, Kahveci et al. 2006, Anderson et al. 2010) Few studies have examined what motivates mentors to do what they do, and how they perceive their roles in practice in different settings, with a particular focus on the fields of engineering. Given the current situation, where women engineers are still in the minority, it is crucial to get a better understanding of who these active mentors (both men and women) are, and what they do at the coalface playing the 'connecting' role between women and engineering fields. Their perceptions and views are of vital importance to engineering education.

Ultimately, this study aims to fill this gap in research by shedding light on mentors' motivations for supporting and nurturing female engineers, and canvassing their views on how mentors can best help, based on their experiences. A particular focus is placed on the interaction between cultures, institutional settings and individuals in the mentoring relationship, including their genders. These three (cultural, institutional, and individual) dimensions have been identified as significant for explaining women's underrepresentation at higher job levels (Ragins and Sundstrom 1989, Fagenson 1990). Adapting a conceptual model of learning processes at different levels (Hoeve and Nieuvenhuis 2006), for the sake of simplification, a culture is defined in this paper as perceived norms within a national boundary, and institutions are conceived in terms of a simplified dichotomy between academic and non-academic (government and business) entities. The diagram below (Figure 3) outlines each of the three factors (socio-cultural, institutional and individual).

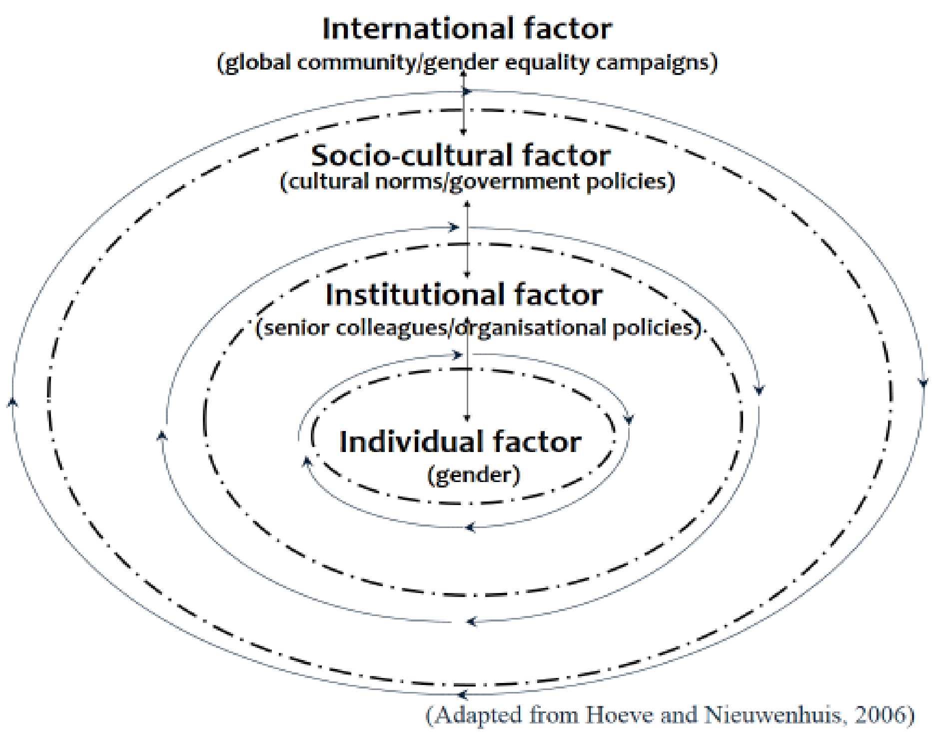

Figure 3 Diagram showing interactions among international, socio-cultural, institutional and individual factors

The study examines the following three key issues within the above context: (i) mentors' motivations for supporting female engineers; (ii) mentors' experiences in supervising and mentoring them, and (iii) mentors' views regarding officially recommended actions to increase female leading researchers' numbers in engineering. The research questions include: what motivated a mentor's decision to become a mentor? What factor influences mentors' approach to their (female) mentees? Is there any difference between mentors in academia and industrial research settings, in their approach to mentoring female engineers? What actions do mentors recommend for increasing and nurturing female leaders in engineering?

Methods

In order to meet the above objectives and obtain more in-depth information to enable us to answer our research questions, we adopted a qualitative research design for this study.

Participants

Purposive sampling was used to select participants we deemed most able to provide information relevant to the objectives of the study. 'Mentors' (n=25) leading research groups in the field of optical engineering were selected as a representative domain. Mentors are defined as 'individuals with advanced experience and knowledge who are committed to providing upward support and mobility' to their mentees' careers (Ragins and Cotton 1996: 529). All the participants self-identified themselves as 'mentors', although they are not all necessarily appointed 'officially' as such in their affiliated organisations. Therefore, they are in most cases 'informal' mentors, as opposed to members in formal mentoring programmes (Ragins and Cotton 1996). The inclusion criteria were that 'mentors' had to have 20 or more years of experience in conducting research, must have been supervising junior research students, and must have been an advocate for supporting young female engineers. They were all affiliated to an international academic society of optical engineering, which covers a broad range of subjects, from astronomy and biomedical optics to electronic engineering; this field has experienced the issue of women's underrepresentation for a relatively long time. This particular academic society has members from both academic and industrial research settings, and has been vigorously promoting the participation of women in those subjects through various activities such as speaker series, outreach programmes and the creation of a calendar featuring many female scientists from all over the world since the 1990s. The ratio of female members in the society is currently 16 per cent, while 25 per cent of committee roles are filled by women, due to their active commitment to drawing more women into engineering and leadership positions. An international conference of the society, which is held annually in San Diego, USA, was targeted as the best arena to recruit and interview as many mentors from different countries as possible.

Additionally, we recruited early-career researchers either in their postgraduate studies or within three years after their completion of doctoral degrees during the conference's networking event for female researchers to complement the data obtained from the mentor interviews. The primary aim here was to understand mentees' perceptions and experiences in the field of engineering.

Data collection

Given the relatively small number of female research leaders in engineering, while semi-structured, face-to-face interviews with experts were the primary method, telephone interviews using the same topic guide were also used as a means of broadening participation.

The original topic guide for the interviews were developed and piloted with two key informants (both in the field of optical engineering) and revised before being completed by the participants.

All participants in the study were first asked to identify the major factors that influenced their decision to support female engineers. They were then asked if they had observed any difference between their male and female mentees in behaviour, career choice or any other aspects of life. Lastly, they were asked to given their own recommendations for increasing the number of female leaders in engineering.

As previously mentioned, the sampling method was primarily purposive, and most participants were identified by the above mentioned pair of key informants, who are themselves actively engaged in mentoring female engineers. The identified participants were invited one month prior to the conference via email, and the times and the dates for the interviews were agreed beforehand. The snowball sampling technique was also used for the duration of the conference to increase the number of respondents. All the face-to-face interviews were conducted in a private room away from the conference activities during the five-day conference in August 2011. As for those who could not attend the conference, seven mentors (all female) were invited for a telephone interview. The telephone interviews were conducted in October 2013.

Table 1 shows final numbers of participants interviewed by sex and affiliation (i.e. academia versus industrial research settings).

Table 1: By affiliation (n=25)

	Academia	Industrial research settings	Total
Men	4 (16%)	4 (16%)	8 (32%)
Women	9 (36%)	8 (32%)	17(68%)
Total	13 (52%)	12 (48%)	25

Participants

Out of 48 mentors initially contacted, 25 agreed to take part in the study. All interviews were digitally recorded and transcribed verbatim for transfer to files for electronic processing. Mean interview time was 26.6 minutes, with the range being from 15 to 45 minutes.

Participants' average years of experience in the field were 31.1 years. In total, we had 25 participants. We conducted 18 face-to-face and 7 telephone semi-structured interviews. The ratio of women to men is 17 to 8. The countries represented in our data include the United States (11, 44%), Japan (four, 16%), Spain (four, 16%), Mexico (two, 8%), followed by Australia, Canada, Italy and Sweden (one each, 4%).

Regarding the mentees, six early-career researchers (two doctoral students and four post-doc researchers; five female, one male; two each from USA, Japan and Spain) were interviewed. They were asked about their experience of being in the field of engineering and having a mentor. One male researcher was in attendance at the networking event for female engineers, and volunteered, as his wife (who was not there) is also an engineer. Their views will be referred to, where appropriate, in the result section.

Local research ethics approval was sought, and written consent was obtained from all participants. They were informed about the study's aims, estimated interview duration, confidentiality and their rights to withdraw from participation prior to the commencement of data analysis.

Data analysis

Data were analysed using QSR NVivo 9.0 data analysis software. All interview transcripts were stored in a single file so that the authors could access the data and iteratively develop a final coding framework for the analysis using the constant comparison method (Charmaz, 2006). The initial coding framework was based on the interview schedule, while the final coding framework was built to reflect emerging themes and to link the ideas expressed by participants. In order to further ensure the reliability of the analysis, two coders separately examined portions of the transcripts and resolved any differences. The final coding framework consisted of the mentors' profiles, their own experience as research leaders, their observations as mentors, and their views and opinions regarding recommended actions for improving the situation surrounding women in engineering (Appendix 1).

Results

This results section presents the findings by providing quotes from the interviews which were assessed by the coders as being representative of the responses received.

Motivations for nurturing female engineers

Gender stereotypes experienced first or second-hand

When asked about their motivation for supporting female researchers, most participants shared personal episodes in their many years of professional as well as personal life. While gender stereotypes were the main obstacle for female mentors in pursuing their goal of entering the field, only one male mentor perceived any obstacle deriving from gender issues.

Out of 17 female mentors, only one respondent answered that there was no difficulty caused by her gender. However, she then went on to discuss how she did not make an issue out of her male colleagues' discriminatory attitudes. On the other hand, out of 8 male mentors, only one mentioned that he was sidelined by his female boss for a long time and he believed that there was a gender element to it.

Despite this difference in the degrees of direct experience between male and female respondents, male mentors had a strong awareness of women struggling in engineering or other STEM fields, from their experiences of sharing the burdens women experienced or witnessing hardships in their home environments – e.g. as brothers, partners or fathers.

One male professor gave a vivid account of family dynamics that determined his sister's future career as a science teacher.

> "I'll never forget this because my mother stepped up and my mother said well if you educate a man you have an educated man, if you educate a woman you educate the family. And so then she did go to college, my sister, well because of my mother. I think it's the strong mother who made that possible." (male, optics, academia, USA)

Another male mentor talked about his wife, whose original dream of becoming a mathematics teacher was dashed by her teacher.

> "My wife had a strong interest and strong inclination towards mathematics. And she was educated in a very good school.... But she was advised by her teacher not to study mathematics, that it wasn't for a girl." (male, optics, industrial settings, USA)

Some male respondents also discussed work–life balance issues, from the perspective of being a supporting partner for their working wives, or as fathers.

> "As a man, I did not have particular issues or problems, but as my wife was also a working mother, when my children were small, I too juggled with my work–life balance." (male, optics, academia, Japan)

While male mentors saw their motivations stemming from their experiences through their close relations, female mentors naturally emphasised their own experiences of facing difficulties as a main driver for their choice to become a mentor.

> "When I was in nuclear physics I was the only woman, and I'm a different kind of person, I like working on my own, I'm a little bit unconventional, and that can be confounded with gender bias, reactions because of gender. So I really had a hard time in graduate school because of that, but not just because of gender bias, it was because I was by myself, I was alone and I didn't have anybody with comparable experience to speak with that I could really confide in and they would understand what I was going through…. And back then obviously there was no mentoring scheme or any support." (female, nuclear physics, industrial settings, USA)

Discrimination in the workplace

With respect to professional life, discrimination in the workplace has also affected the majority of female mentors. Eight of 17 respondents reported discrimination at recruitment as well as at promotion, and four mentioned that they were not given support by their senior colleagues.

> "I had a two-year-old and my husband's a grad student and we needed to find some money, so somebody said well we have technical colleges… So I went for an interview and they actually said

> we have to hire a woman, and …I didn't really want to take the job, I said people are going to just hate me because they know I got this job because they needed a woman. And I had an engineering position at the same time but I really love teaching so I thought who'll know. Well everybody knew, and the first year was just awful, they called me *John* because *John* was the fellow they really wanted to hire." (female, optics, academia, USA. Name, italicised by the authors, has also been altered.)

Nine female respondents felt that it took them much longer than their male counterparts to receive recognition for their work.

> "Promotion was always suggested at least five years later than my male counterparts." (female, optics, academia, Japan)

Although for male mentors, discrimination in the workplace was not the direct motivation for becoming a mentor, some male participants concurred with the issue of promotion.

> "Well I think a woman in science, […] has to be much better than the corresponding man in her capability, no question about it. I mean a man will get promoted to be Vice President or Project Engineer, a woman will probably not get promoted, at least my experience within the few industries that I've worked with. A woman has to be much better to get promoted to be a Project Engineer than the corresponding male." (male, optics, academia, USA)

On the other hand, when becoming a mentor or an advocate for female colleagues, the hurdle seems to be higher for men. One male mentor confided how difficult it was for him to voice his opinions in favour of his female colleagues' promotions, as that would have been seen as a breach of conduct in the male-dominated 'club'. In their many years of professional life, all male participants in this study have collaborated with women, if not in private in the home then in research, and were convinced that there was a need for them to take part in ameliorating the situation for women in engineering. The fact that this study had fewer male participants also indicates this difficulty.

Strong cultural norms in society: the third dimension?

For female mentors from certain countries where traditional cultural norms are still strong, these issues were frequently mentioned as a major reason for justifying the existence of mentors. Two strategies mentioned to overcome difficulties with respect to work–life balance illuminate this issue. One was to get support from parents, partners, or even students. The other was the opposite of this: the decision not to have a family. The latter category was explicitly mentioned by a few respondents from one particular country.

One of the reasons was that “since I had no female role model who had achieved both career and family, I could not see the long-term consequences of remaining unmarried” (female, optics, academia, Japan). Another answered that “I avoided career difficulties, I dare say, by deciding not to have a baby at all” (female, optics, industrial settings, Japan).

Several examples were provided concerning cultural biases that women had to combat.

> “for instance, I was pressed to leave my position for a man because he was going to get married, he was going to take responsibility of the family, I was single, so things like that which are clearly related with gender. But I have always fought against these gender and cultural prejudices” (female, optics, academia, Spain).

These mentors argued that they would like to protect the younger generation of female engineers from these societal pressures or strong cultural norms, while demonstrating directly that the new generation could do it in a different way.

> “I liked to be a mentor. I am a mentor in a natural way because I advise them, try to protect them, and to direct them…” (female, optics, academia, Spain).

Three major driving factors for their mentoring activities were identified here. No difference was found between institutional types (academia or industrial research settings). These accounts demonstrate that the primary motivation was similar between men and women; and of a personal nature, though women with direct experience expanded more on why they thought they could be a good mentor. One reason was that they could share the knowledge about the cultural or social dimension, particularly in relation to their private life choices. Their personal life choices were influenced by perceived cultural factors, and the notion that they need to be addressed has defined their roles as mentors. The other reason was to highlight more positive aspects of being a woman in engineering and show that they could take an active role in it. The next section deals with participants’ experiences as mentors for female researchers.

Mentoring experience and observation of female engineers: difference between male and female mentees?

Both male and female mentors were asked if they observed any gender differences in their groups of supervisees both at individual and group levels, and whether they adopted a different approach to their male or female junior members.

For the first question, almost half (12 out of 25) reported no difference in the way they approached their research, work and lives.

> "Not really, because technical students are technical students." (female, optics, academia, USA).

While some had qualified answers, those who noted any gender differences reported that they adjusted their approach accordingly. Therefore, more than half of the mentors implicitly replied affirmatively to the second question.

> "Women are by far more responsible with answering to specific tasks/duties. I have to use, then, more accurate wording with my female students and colleagues. They are very good at organizing team work, propose new (innovative) ideas for research, and for outreach programs." (female, optics, industrial settings, Mexico).

Even when their explicit answer was: 'I don't think that I really differentiate between male or female' (male, optics, industrial settings, USA), some answers implied that mentors recognised the need to give more attention to their female mentees.

> "Problematic to generalise… but there are differences. Women accept a larger support role, in family, a larger support role in many respects…women tend to have quieter voice than men" (male, optics, industrial settings, USA).

Differences between male and female mentees (1): group dynamics

The last point was echoed by many mentors, both male and female. In a group or institutional setting, women are described as less assertive, more self-critical, and often lacking in self-confidence. Many respondents referred to group dynamics which impacted more on female students or colleagues than their male counterparts.

> "I have noticed that a lot of times when they're working in the lab that if something goes wrong in the lab the male students typically will blame that she did it, but that's about the only thing that I've really observed and I sort of put that down … And as it turns out, I mean it wasn't her mistake, it would be the male's mistake, so." (male, optics, academia, USA)

Several corroborative anecdotes were also provided.

> "When we did robots…you'd have a competition for the robots… we mixed up women and guys, the girls and the boys and then we had just all girls … and so the boys would do their thing and the girls would do their thing but when you put the boys and the girls together the boys would start to dominate and they'd push the women to just be support… and but then I noticed the women's team won, the all-woman team won …because the boy and the girl they weren't utilising each other, boys weren't utilising the girls' skills …and so they essentially cut themselves down to half a group trying to make decisions instead of a whole group trying to make decisions." (male, electronics, industrial settings, USA)

Many mentors recognised such group dynamics as a reason for their interventions, as one that mostly affects female mentees in a negative fashion.

However, with regard to single-sex education, mixed views were expressed. Some of the respondents from the US have had first-hand experience going through single-sex education, and they argued there are benefits to keeping it. For other participants, especially from Europe with not much exposure to such institutions, the idea of single-sex education appeared to be at odds with the principle of equality and their real-life experiences. Therefore, individual experiences and exposure to the institutions in their respective cultural environments had some impact on their opinions.

Difference between male and female mentees (2): career selection and perceptions towards academia

Many mentors shared the perception that when their female mentees choose their specialisation within the range of engineering subjects, they tend to go with biomedical optics, rather than electronic optics. They also prefer people-based professions, such as science communication and teaching, to continuing in research or staying on in academia, which is often considered to be a solitary and tough place for women.

> "They have gone into teaching and also I have some of them, two of them were physicists in the hospital assisting the doctors […] So I have some examples of women who were more interested in applications for biology, medicine rather than more abstract theoretical aspects." (female, optics, academia, Spain)

In terms of choosing academic or industrial research settings, the general consensus among the participants was that academia is less female-friendly.

> "There are some hinderers that women experience in pursuing an academic career and I hear it all around me. It's perceived as very hard, it's perceived as there are no excuses, no space given for recognition of things like having a family… and even if funding agencies are saying that they are taking into account in real world there is a lot of doubt whether they really are taking into account all those things …" (female, optics, academia, Australia)

Mentors in both academic and industrial settings agreed that academia is seen as harsher towards women.

> "I spend a lot of time talking to companies, getting students into companies, finding them jobs…My companies don't care, my companies want competent people, men or women" (female, optics, academia, USA).

> "It's been more of which environments you are in. The environment I am in now is a research environment […] highly educated environment […] people already have PhDs in the organisation […] certainly even some of the chief engineers […] are women." (male, optics, industrial setting, USA).

In academia, there is still considerable scope for discretion, and therefore, informal support is essential for female researchers to feel safe and remain active when they start to have their own families.

Key strategies for tackling gender difference and ensuring gender balance in the workplace

Participants mentioned a couple of strategies for supporting female scientists in their work place. In particular, mentors in academia adopted a more informal and collectively agreed approach to recruiting, selecting and promoting women in order to ensure a better gender balance in their research groups.

> "It's informal but definitely present, when the department gets applications, it does pay special attention to the applications from women […] it's often the case that you have more […] good students, than you have slots available and so, at the level where it's coming down to random chance, we will try to encourage women and a number of the faculty do try to keep track of the good women in their classes and let them know that graduate school is an opportunity that is available and many surprising number of undergraduates don't seem to be aware that you can get teaching and research fellowships to go to graduate school." (female, optics, academia, USA)

> "What we say at home is when we select new PhD students we say that we need a mixture because otherwise there are only boys, which happens sometimes that we have more boys than girls, the atmosphere in the research group is more …competitive." (female, medical optics, academia, Sweden)

With regard to support for female students, in both individual and group situations, it was suggested that closer observation, mentoring and support are necessary.

> "I think we've put working in a team as being very important and I think that there are issues there in gender roles, in how males and females work in teams that we have to pay attention to…." (female, computer science, academia, USA)

> "Those who want to do it will do it anyway. I mean those who are absolutely a hundred and fifty percent determined to do it. They will find a way to do it but those who start hesitating because things get very, very difficult… and they don't get encouragement, it's easier to get out of academia." (female, optics, academia, Australia)

Having spent many years in supervisory roles, participants are attuned to both individual and gender differences. The results show that there is a growing sense that a mixture of men and women in a team works better and produces better results. In academic institutions, many mentors discussed their key strategy to recruiting, selecting and promoting women in order to ensure a better gender balance in their research groups, if not at university-wide level.

The next section looks at mentors' views on recommended actions for nurturing female engineers.

Difference between academia and industrial settings

No major difference was found between academic and industrial research settings regarding responses about the significance of mentoring. However, the data seem to confirm that providing informal and personal support, while recognising independence of a researcher at the same time, is regarded as highly important in academia. In industrial settings, 'clear visions and goals' and 'clear communication' are more highly valued.

> “I have worked a little bit on the academic side of things, the academic side of things is a much more of a democracy and occasionally I point out to people in our own organisation, well, this is an industry, this is not a democracy and at some point there is somebody who is responsible for the execution of a project … and that person has the final say in things.” (male, optical engineering, industrial settings, USA)

Cultural factors: Diverging views on social change and barriers for female engineers

Mentors who mentioned the issue of cultural biases demonstrated more concern about perceived positive changes in society for women in STEM over the years, and believed that their roles as mentors needed a more personal approach, sometimes even alerting young female researchers about possible future challenges. In this respect, cultural factors resulted in a different focus on their perceived roles.

In general, most interviewees regarded recent social change as positive for women in engineering.

> “Well you know the women that I see in my classes, they have no idea what it was like in those old days […] I met a young woman who was at a technical high school, which is where we do most our recruiting from, and I said why are you in electronics? She was a very beautiful Hispanic girl and she said I just like to know how things work. And I thought ‘well good for you, I’m recruiting you for my programme!’” (female, electronic engineering, academia, USA)

All of the six early career researchers interviewed confirmed this positive view, as they noted that they had experienced no personal hardships so far because of their gender.

> "I had no difficulty so far, but I heard guidance counsellors (in my secondary school) telling people, oh you don't want to go into engineering, telling it to a girl, and I never had that problem"

"I only have technical problems such as skills to do experiments and write articles in English. I can always turn to my supervisors and mentor even if I have personal difficulties, which is great"

Some remarkable differences were found from country to country among mentors. Most participants from the United States (both academia and industrial settings) reported that most blatant forms of discrimination had been eliminated, and when they mentioned cultures, they were largely referring to different ethnicities (Hispanics, Chinese etc.) or disciplinary differences (heavy manufacturing areas versus chemistry/biosciences areas).

"The outright form of discrimination I think we've largely eliminated, and even for the more subtle things, we work hard to eliminate them by providing programmes." (male, nuclear physics, industrial settings, USA)

In contrast to this, for those who mentioned cultural factors as the single major obstacle, even today, to many women, the word culture meant the conventional societal value system of 'men at work, women at home'.

"Although time has changed many things, the feeling that women are not so well fitted to work in science is still very widespread." (female, condensed matter physics, industrial settings, Spain)

"There are still cultural barriers that prevent women from working at high levels in all fields, because for many centuries women were only considered important for their families and home activities." (female, optics, academia, Italy)

Some mentors define their mentoring roles accordingly.

> "Now I observe there are young girls who consider that they are not in difficulties because of their gender. So when they are about 25, 26 they have finished their degree of physics very, very well and they are doing their PhD studies. So I talk to them, and sometimes very openly saying maybe this is the age where you do not realise this difference because you have been successful at high school, you have been successful in the PhD, but maybe you are going to face these difficulties when you start planning to get married, to have children." (female, optics, academia, Spain)

These cautious attitudes toward this positive trend in society were more strongly expressed by those who reported cultural biases in their countries. They regarded their more hands-on, nurturing or often directive mentoring styles as a necessary countermeasure against these cultural biases found in their societies. The data suggest that cultural perceptions of the mentors seem to be one of the major factors that influence their mentoring styles.

Recommendations

More women into leading positions

In terms of recommended actions for improving the situation of female engineers, participants' responses confirmed previous studies' findings (e.g. greater visibility of female scientists in basic or applied STEM subjects, more information about multiple opportunities where girls could use their talents, more investment to be made to training for science teachers at primary and secondary school levels, and improvements in infrastructure such as child-care and elderly homes). However controversial it may be, promoting more women to higher positions (including fellows in an academic community, board of executives and committees) was also considered necessary. The preferred way of achieving this might be formal (e.g. quotas or targets) or informal, depending on cultural or institutional resistance.

All participants emphasised the need for further promotion of female engineers to leadership posts, as there are still very few. The presence of a female leader in the field sends out a positive signal to other women.

> “when I was in the industry in Silicon Valley, I was the only woman…I mean it isn’t the matter that you’re going to walk out of there because you are the only woman; it is because you have to have your presence. I have many female students that come to me and say thank you for being here because you are my role model. I think, ‘Oh my gosh, okay.’ I can’t believe that, but if this helps, I’ll still be in here, even though it’s not easy.” (female, computer engineering, academia, USA)

In addition, a few participants recommended that the percentage of women in senior positions should be made an item along with other performance indicators for an institution.

Women mentoring women or joint mentoring

Both male and female participants mentioned that female supervisors could offer a different kind of mentorship to their research groups.

> “Mentoring styles of men and women are somewhat different, complimentary ...” (male, optics, industrial settings, USA).

Referring to a woman’s way of mentoring, “I suppose it’s much more caring way of bossing them around…I think that probably women do have some way of connecting on a little bit more of a personal level..." (female, optics, academia, Australia)

Although generally, mentors agreed that female researchers prefer having female mentors, there was a divergence of opinions regarding the merits of women mentoring women. A few female mentors reported difficulties they had in supervising female students.

> "When a woman supervises another woman, she needs to take a very hard role. She has to be in a difficult equilibrium between being a good friend, a good supervisor and a serious researcher. If she becomes more demanding and critical about the work of the student, this is usually not very well understood." (female, optics, academia, Spain)

With regard to the issue of work–life balance, female mentors who are juggling their work–life balance with their students also will provide learning opportunities for the next generation of researchers, men or women.

> "[…] it's going to take a couple of generations to change but as more women become in charge to show that they can do it better or as well as the men can and then as the younger generation get used to having these female role models." (male, electronics, industrial settings, USA)

Both male and female participants felt that given careful management and the backing of a leader in the group, the increase in female numbers and their working together in a mixed-sex environment could bring about learning opportunities for both men and women and enrich the field of engineering as a result. For the same reason, joint mentoring by a man and a woman was recommended by several mentors as a complementary model.

Discussion and conclusion

When asked about their motivations for the active promotion of female engineers, all female mentors reported many personal difficulties and challenges, irrespective of participants' cultures and institutions. Male participants in this study had strong awareness of women struggling in STEM, often from their experience of sharing the burden or witnessing hardships in their home environments. This finding highlighted both the positives and negatives of the current situation facing women in engineering. The positive is that these male and female mentors are equally committed to nurturing female engineers for the sake of a brighter future for their disciplines as well as for society in general, through their activities at national and international levels. They firmly believe that more women in engineering are capable of taking up leadership roles. Their views, backed up by their anecdotes, are in sharp contrast to the findings of a recent study by Moss-Racusin et al. (2012), which highlighted gender biases among both male and female academics against female students specialising in science. On the other hand, the negative is that their primary motivation for becoming mentors is still personal, which suggests that their views may not be embraced and shared widely beyond this circle of informal mentors within this particular discipline. As Ragins and Scandura's study (1999) indicates, informal mentoring relationships are a critical resource for retaining and nurturing employees for an organisation. This applies to the field of engineering as a whole. Institutions in both industry and academia need to not only deliver formal mentoring programmes, but also to further look into ways in which potential mentors can be reached.

Furthermore, although there was a general consensus that the situation has improved for women in engineering over recent years, respondents from some countries believed that cultural biases towards women still constituted a significant major obstacle to the advancement of female scientists in their countries. In particular, participants from Italy, Japan and Spain referred to persisting cultural biases as a cause for concern. This seems to have had some impact on their perceived role as a mentor. The group of mentors from these countries see themselves as personal as well as professional mentors, sharing the scientific knowledge of their subjects as well as life skills needed for advancing their careers. They offer warnings as well as hands-on advice to prepare young researchers to deal with their future hardships. In those cultures, mentors were more likely to be frustrated by the current speed of change and the status of women.

The interviews with mentees revealed that the younger, early-career researchers are much more optimistic about their future, based on their experiences that have been free from discrimination thus far. Mentors from countries where fewer women are active in the labour market not only seek to impart professional skills as a role model, but also pass on their personal knowledge about networking and problem-solving skills, while giving warnings about possible adversity they might face at various life stages.

Another area of general consensus among all participants was that gender difference was commonly observed in group situations, as well as in female colleagues' choices of certain specialisations and career paths. This echoes 'gendered occupational choice' narratives discovered and examined by Powell et al.,(2012). The fact that women's career and specialisation choices seem to be influenced by entrenched gender stereotypes also underlines the significance of informal mentoring. The observed disadvantage for women arising from group dynamics in a mixed-sex situation also points to the merit of single-sex classes that have been found in some empirical studies. Kessels and Hannover (2008) reported higher physics-related self-confidence amongst girls from single-sex physics classes than those from coeducational classes. However, the issue of single-sex versus coeducational schools, in relation to their impacts on girls' STEM identify formation, continues to be debated (Hughes et al. 2013, Sills 2012). The majority of the participants in this study were in favour of mixed education, while being fully aware of the dangers. Vigilance against these pitfalls, and interventions, where necessary, were included in their role specifications for good mentors.

Additionally, as suggested by previous studies (Hopkins 2006, Timmers et al. 2010), academia was identified as a less family-friendly institution, or perceived as such by many women in engineering (Minerick et al. 2009). It was argued that the greatest challenge in academia is to establish a fair balance between a transparent, merit-based evaluation system and a clear signal to female academics that they will be supported and not penalised when raising their children. In industrial settings, formalised rules such as reduced working hours have begun to change the highly masculinised sectors. (Herman & Lewis, 2012) As previously mentioned, the choice that some female mentors had to make between family and career was particularly an acute problem in certain countries. However, unequal career development patterns for women (e.g. delays in promotion) and assimilation into male-dominated cultures of engineering are well documented and remain a great problem (Mcllwee and Robinson 1992, Powell et al. 2009).

The main differences in opinion among mentors were underpinned by their gender, type of institutions (academia or industry) and culture, to varying degrees. A hurdle seems to exist for men interested in becoming a mentor for female researchers. This echoes difficulties of cross-gender mentoring relationships highlighted in studies such as Ragins and Cotton (1996). Although some hurdles to cross-gendering will always remain such as sexual issues and sex-role expectations, recent studies point to the quality of mentoring rather than the gender of the mentor as deciding the experience of mentees (Msila 2013). This study also demonstrated that in practice, male mentors often provide joint mentoring with female colleagues.

With its small overall sample size and disproportionate number of participants from the US, this study cannot provide hard evidence to demonstrate how cultural factors influence individual decisions of women in engineering. A large-scale, cross-cultural quantitative study would be desirable. However, what the study indicates is that cultural as well as personal and institutional factors are affecting how mentors define their roles and mentoring styles. The study has highlighted how mentor-mentee relationships are shaped by multilevel factors, and offers a base for further study. As engineering remains the discipline with the lowest representation of women, to answer the ‘why so few?’ question, the ‘human-system interaction’, including the role of engineering education, needs to be addressed. The socio-cultural system in which the interactions between mentors and mentees occur is one of the key facets that need further research. The seemingly limited pathway for becoming a mentor, particularly for men, also needs to be examined. In order to attract global talent to engineering, a more equitable education and training system must be established. The study also has a limitation in that mentees’ participation was so small that whether or not mentees’ positive perceptions will change over time as they progress in their careers, depending on the types of affiliations or countries, could not be captured.

However, this study has shown that the mentors at the coalface of educating and guiding female engineers believe that, just as in the corporate world, the more female leaders in engineering there are making a contribution, the more society will benefit, as they will serve as role models for their female followers as well as for future generations of engineers, both male and female.

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Appendix 1 Coding framework

Theme	Sub-theme
Profile	Roles and years of experience
	Areas of expertise
	Mentorship and supervision
	Motivations for becoming a mentor
Own experience	Gender difference
	Difficulties and overcoming challenges
	Mentorship and supervision (as a receiver)
Observation/experience as a mentor	Gender difference
	Difficulties and overcoming challenges
	Mentorship and supervision (as a provider)
Views and opinions	Gender difference/stereotypes
	Changes in society
	Difficulties and overcoming challenges
	Mentorship and leadership qualities
	Recommendations